The Effects of the San Francisco Oil Spill on Marine Life

by gordon chan

College of Marin • Kentfield, California 94904

A STUDY OF THE EFFECTS

OF THE SAN FRANCISCO OIL SPILL ON MARINE ORGANISMS

PART I

by

Gordon L. Chan

January, 1972

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ABSTRACT

The San Francisco oil spill occurred on January 18, 1971, during the early morning hours when two Standard Oil vessels collided almost directly under the Golden Gate Bridge, releasing 840,000 gallons of Bunker C fuel. This asphalt-like oil was washed up on intertidal shores of the area.

Duxbury Reef, northwest of the Golden Gate Bridge, is literally the "backyard" of the author and the College of Marin's Bolinas Marine Station staff. Baseline transects have been established on this reef since 1958. The oil was heavily deposited on the reef's mussel beds and high tidal berm rocks.

From comparative transect and laboratory observations, it was determined that marine organisms died from being smothered by the oil, with certain species, such as acorn barnacles and limpets, suffering the highest mortality at Sausalito and on Duxbury Reef. Comparison of pre-oil and post-oil transect counts showed there was a significant decrease in marine life after the oil spill on the reef. Marine snails suffered less mortality than the sessile barnacles and other sedentary animals. The normally large population of striped shore crabs is missing from the rocky crevices. Finally, marine algal blooms were also observed in certain reef localities.

The present condition of Duxbury Reef (December, 1971) is one of apparent good health; the recruitment of some marine animals appear to be approaching normal levels. The oil has disappeared from much of the reef surfaces and is barely discernible in the most heavily deluged areas. Continued studies will be aimed at watching the effects of oil on the recruitment of marine life throughout the afflicted areas of the Marin County coastline.

ACKNOWLEDGEMENTS

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With the unconditional support of the above agencies for this study and with the guidance and publication review by Dr. Cadet Hand, Director of the University of California Bodega Marine Laboratory, this report is the first of two publications dealing with the biological effects of the San Francisco Bay Area oil spill of January 18, 1971. The second report will be published around January of 1973.

My foremost indebtedness is to my wife Maxine who labored hundreds of donated hours compiling the statistical data and typing this report. My colleagues, Craig Hansen and Al Molina of the Bolinas Marine Station, contributed much scientific information, publication review, and guidance throughout the study period. The use of students to assist in data collection in the many preceding years was a vital factor; their names appear in Appendix 1, and I have deep appreciation for their loyalty and competence towards our marine work. Professional consultations were provided by Dr. Cadet Hand, Dr. Lawrence Lowery, Dr. Jack Spence, Dr. Dale Straughan, Dr. Pat Wilde, Jon Standing, and James Rutherford. Their expertise was a necessary part of the research work. Finally, to the many other individuals: Marin County officials, Supervisor Peter Arrigoni and Pierre Joske, Director of Parks and Recreation; United States Senator Alan Cranston; Charlene Corcoran of STOP: John Smaile, Director of the Pt. Reyes Bird Observatory; the Pt. Reyes Park officials; and many conservationists throughout the San Francisco Bay Area--to them go my profound thanks for all their words and works of encouragement.

Gordon L. Chan

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Cover: Dead limpets from the effects of oil, Duxbury Reef

I. INTRODUCTION

The sea has been a vast dumping ground for the pollutants of the world. In many areas of the Pacific Ocean, oil has been seeping naturally into marine waters for millions of years, as in the Santa Barbara, California area. Through the advancing technologies of man, oil has become a pollutant because man has purposefully and accidentally spilled oil into the marine environment and harm has consequently come to its inhabitants.

In 1971 a report estimated that an accumulated total of 1.5 billion gallons of crude or petroleum products have been spilled into the oceans of the world (1). The tanker "Torrey Canyon" alone spilled an estimated 29.4 million gallons of oil off the coast of Cornwall, England, in 1967 (1). On a smaller scale, in San Francisco Bay during the early morning hours of January 18, 1971, two Standard Oil tankers in thick fog collided and released some 840,000 gallons of an oil called Bunker C into the tidal channel under the Golden Gate Bridge.

The tidal currents carried the heavy asphalt-like oil about fifteen miles north of the Golden Gate Bridge and deposited it on a low-profile shale intertidal area, Duxbury Reef near Bolinas, California (Figure 1). The reef was blanketed in certain areas with this thick marine fuel. Since 1958, I have employed baseline transects and have measured and counted many thousands of marine organisms on this reef. The analysis of the damage to this reef is the objective of this report.

II. SCOPE OF THE PROBLEM

Although this report will discuss biological changes, the total ecological damage from the oil released from the collision of the Arizona Standard and the Oregon Standard may not be known for many years, if ever. Two scientists from Woods Hole Oceanographic Institution, Blumer (4) and Sanders (2), analyzing the September, 1969 oil spill off West Falmouth, Massachusetts, are still finding damaging effects to marine organisms after one year of study. These scientists employed a full range of chemical and biological analyses of the oil spill. Such is not the case with this College of Marin report. Our focus is on the biological observations of the author and his students over a period of fourteen years.

Dr. Cadet Hand, Director of the University of California Bodega Marine Laboratory, is also making biological and laboratory investigations on the effects of oil on marine organisms. My study which was conducted almost wholly on the reef is a supplement to Dr. Hand's work and that of other individuals researching the scope of ecological damage from this oil spill.

In my review of literature concerning the ecological results of recent oil spills throughout the world, the conclusions have ranged from "very little mortality"(3) to "massive kill"(4) of marine organisms. It is apparent that the oil spills which have polluted the ocean were, in general, different in chemical composition from each other. The San Francisco oil spill of January, 1971, consisted of Bunker C fuel oil, and our data presentation and conclusions here (and in the proposed second report of January, 1973) will be pertinent only in regard to this specific fuel. Since the Duxbury Reef transects were established before this spill, a re-evaluation of these transects will provide a portion of the understanding of what happens when oil is spilled onto a marine environment.

The major hypothesis for this study was that oil spilled on an intertidal reef did kill marine organisms. The null hypothesis was that the spilled oil did not kill marine organisms. If the oil spill did kill marine organisms, the principal problem was to determine the degree of oil damage to marine life. Other supporting assumptions were:

1. Environmental conditions have been relatively stable over the entire Duxbury Reef; that is, storms and other chemical pollutants, besides oil, have not influenced a major decrease in populations within the past year.
2. Natural predators within the environment have not abnormally accelerated their predatory habits within the past year.
3. Finally, with Duxbury Reef protected as a marine reserve under State Fish and Game laws (5), the collecting of marine organisms by school groups and the general public has been greatly reduced.

This report will not discuss the damage sustained by the bird population as a result of the oil spill. However, for the reader's brief review, the California Department of Fish and Game estimated that some 7,000 seabirds were injured by the oil and less than ten percent survived (11).

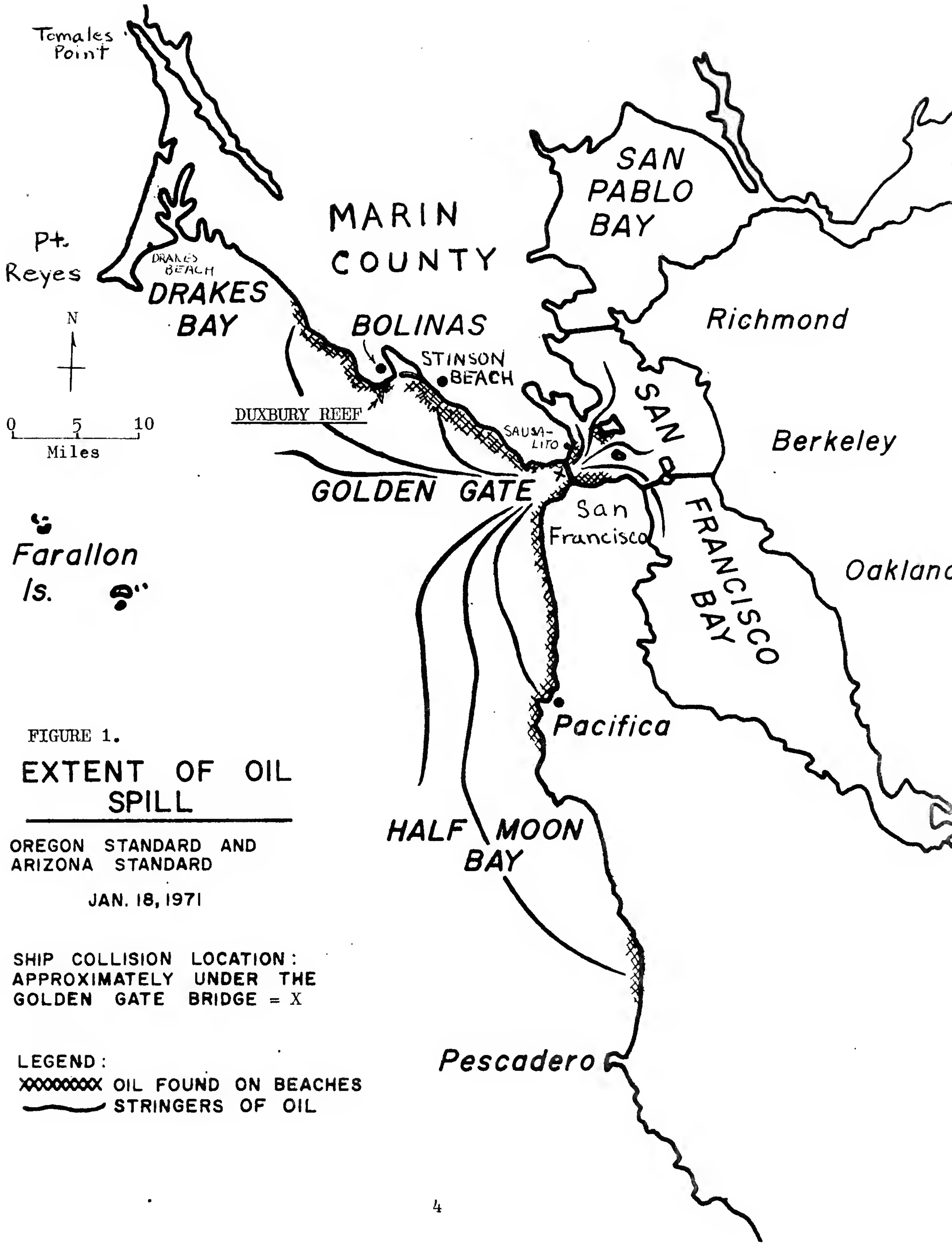


FIGURE 1.

EXTENT OF OIL SPILL

OREGON STANDARD AND ARIZONA STANDARD

JAN. 18, 1971

SHIP COLLISION LOCATION: APPROXIMATELY UNDER THE GOLDEN GATE BRIDGE = X

LEGEND:
XXXXXXXX OIL FOUND ON BEACHES
〰 STRINGERS OF OIL

III. SAMPLING METHODS AND PROCEDURES

A. FIELD RESEARCH METHODS

Direct observation on the reef was the sole field method of investigation. Supportive laboratory and computer calculations assisted the interpretations of our field observations.

Baseline transects were the primary method for establishing reef reference points. In all but five instances, the reef transect placements were chosen from random numbers.

Most transect lines were ten meters long. A plastic rope marked in meter increments was laid along each transect. Square quadrat frames with inside edges measuring one meter were made of wood lath. At least ten decimeter squares were constructed inside each square meter quadrat frame (Appendix 2) for making square decimeter counts of dense populations of small-sized species, after Johnson (6) and Southward (7). For the majority of counting throughout the years, a hand counter was employed to register the totals.

Since 1958, forty-two transects have been established on Duxbury Reef over the years and studied intermittently for a variety of purposes, with 1969 as the year with the most intensive studies. Thirty-three of these transects were selected for this oil study report because of their suitability for repeated studies over the years and their relevancy to the oil contaminated areas. Of the transects used, three were underwater compass transects around the Bolinas headlands. Other transects were located at Sausalito, Fort Baker, Drakes Beach, and Stinson Beach. Appendix 2 contains sample transect data sheets.

A typical reef survey excursion started with the investigators (students or myself) moving out onto the reef. With the marker or transect point as reference (a large glavanized nail or a plastic tube embedded

in cement), the rope was tauntly drawn between the two markers, parallel to the shoreline. At approximately the same tidal height, the square meter frame was moved along the line as counts were recorded for each square meter. The amount of residual oil on transects was "rated" according to the percentage of square meters with oil (Appendix 3) and recorded thusly:

N = no square meters had oil
+ = 1-25% with oil
++ = 25-50% with oil
+++ = 51-75% with oil
++++ = 76-100% with oil

Square meter samples were also given oil designations according to the percentage of the square meter containing oil.

In subtidal transects, the general method used was a compass bearing for ten meters. I have experimented with a variety of methods including weighted lines and square meter frames, but due to hazardous ocean conditions off our Northern California shores, I have firmly held to the underwater compass bearings as the most practical and safe method for subtidal transect studies. The sample totals for subtidal work are treatly separately from the intertidal counts (Appendix 6).

B. STATISTICAL PROCEDURES

Appendix 4 presents the statistical terminology and formulae used in this research paper. The population numbers, particularly the confidence intervals for the population mean and the population proportion, were determined from the data obtained in the sample, using Z tables for sample square meters totaling 30 or more, and t tables for samples less than 30. Test statistics were also used to determine the analysis of variance among sample transects.

The 95% confidence interval is used consistently in this research to determine the interval within which we may expect the population mean or population proportion (8). If, on the basis of repeated sampling,

95% confidence intervals for the population mean, μ, are set up, then approximately 95% of these confidence intervals will actually contain the true population mean.

C. SITE SELECTION

1. Major Study Area

Duxbury Reef is located approximately fifteen nautical miles or about twenty-five road miles northwest of the Golden Gate Bridge and one mile west of Bolinas, California (Figure 1). The reef was named after the ship DUXBURY which ran aground on these rocks on August 21, 1859. The reef (Figure 2) has an area of about sixty-six acres (9) and is composed of Monterey shale deposited during the Miocene Epoch, some twenty-eight million years ago (10). The basement rock below this Monterey shale is granite diorite which is exposed further to the north at Point Reyes Headland, Tomales Point, and Bodega Headland.

The reef was divided into three areas, designated as A, B, and C (Figure 1). Area A, also called Agate Beach, is the area most accessible to the visiting public, while area C, heavily sculptured by flood channels, is least accessible.

The approximate locations of reef transects are illustrated as straight lines in Figure 2 and identified with the transect study site number. Subtidal transects are marked as X-12 on this same map.

2. Other Areas

Stinson Beach, Drakes Beach, Sausalito, and Fort Baker had one transect each, with the transects varying in length from ten to fifty meters. In each of these areas, a site was selected which would best represent the total biota.

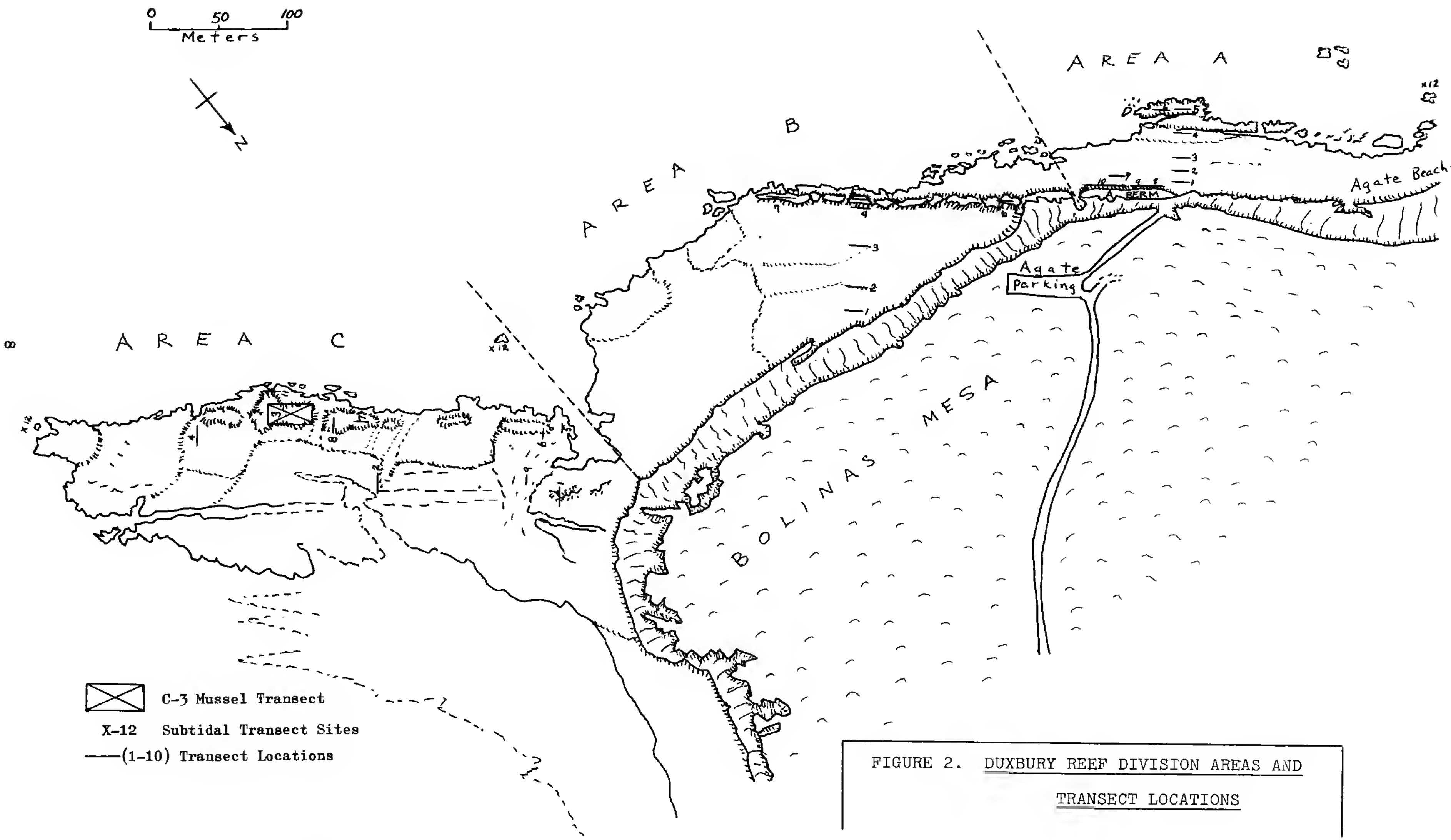


FIGURE 2. DUXBURY REEF DIVISION AREAS AND TRANSECT LOCATIONS

D. SELECTION OF STUDY SITE

1. Observations after the oil spill

My students and I combed the oil-polluted areas from Sausalito to Duxbury Reef in the days following the spill. Dead organisms were recorded and the data is included in this paper.

2. Transect study time

A series of transect observations were made on Duxbury Reef after the spill, but counting organisms while the oil-tar residue was still "tacky" was not practical. Instead, observations of all dead organisms were recorded for the entire reef for the next two-month period, February and March. Strong winter waves may have washed away many dead organisms from the reef during this time. With favorable tides, counts made in April and summer of 1971 were selected as the basis for post-oil spill data comparison with pre-oil spill transect studies.

E. LABORATORY STUDIES

Mr. Craig Hansen, chief technician at the College of Marin's Bolinas Marine Laboratory, headed up a team which developed a series of tidal tanks which simulated the six-hour tidal cycles of our California coast.

Sample Bunker C oil was placed into one tank and allowed to move with the tide every six hours for at least 30 hours, in order to duplicate the time the oil took to move from the Golden Gate to Duxbury Reef. Selected berm and mussel organisms were then placed into these oily waters at low tide to determine effects. Control tanks, free from oil, were set up with similar marine life. This experiment will be carried on for an indeterminate time; the results of a 28-day study period are included in this report.

IV. GENERAL OIL SPILL INFORMATION

A. Collision

On January 18, 1971, about 1:42 A.M., at a spot almost directly under the Golden Gate Bridge, the inbound oil tanker ARIZONA STANDARD crashed into the side of the outbound tanker OREGON STANDARD bound for Vancouver. Approximately 840,000 gallons of oil spilled into the entrance of San Francisco Bay.

B. Oil

As reported by Standard Oil Company, the material is a heavy fuel oil called Bunker C. The oil is used as fuel for ships' boilers or power plant (sawmill) boilers.

1. The oil was a "two-cut mixture" of asphalt (a heavy bottom cut residue from the fractionator) and a lighter low viscosity oil. This mixture has a specific gravity °APl listing as 9.6 which classifies it as a "very heavy oil."
2. The viscosity is at SFS 172, 122°F, which means that temperatures of 122°F to 130°F are needed to make this oil flow. In sea water this oil mixture congeals readily; much of the oil breaks up into suspended globules.
3. The hydrocarbon numbers of Bunker C are:

Carbon numbers	% by volume
C-8 or less	0.2
C-8 to C-21	31.6
C-21 or heavier	68.2

The more volatile oils are those with the lower carbon numbers, and are presumed to quickly evaporate or float away from the heavier oil when exposed to sea water.

C. Cleanup Operations

Standard Oil reported that an estimated 525,000 gallons of oil were

picked up by its collecting methods of skimming in the ocean and bay and straw-gathering on the shore zones.

D. <u>Tidal Current Chronology</u> (as observed by my colleagues and myself)

1. <u>January 18, Monday</u>

a. There was a 5.1 flooding high tide under the Golden Gate Bridge up to 4:06 A.M. The oil was thus washed up onto the high tide rocks of adjacent Sausalito and San Francisco shorelines.

b. The tide began ebbing at 4:06 A.M. and the oil began moving out the Golden Gate entrance. The northwest eddy drift, as described by Dr. Pat Wilde, University of California oceanographer, carried a large proportion of the oil northwest towards the Stinson Beach-Bolinas headland areas.

c. By mid-afternoon, 2:00 P.M., a flooding 3.5 tide brought the oil onto Stinson Beach. At this time and during the succeeding five days, the heroic efforts of the Bolinas-Stinson Beach communities and other volunteers prevented the oil from entering the adjacent Bolinas Lagoon.

2. <u>January 19, Tuesday</u>

a. Duxbury Reef, Area A, began receiving the oil during the early morning hours (4:00 A.M.) brought in by a flooding 5.2 high tide.

b. The low-high flooding tide brought the oil in again to the reef on a 3.3 tide, the flood continuing up to about 5:45 P.M., depositing a heavy stringer of oil on C-3 mussel bed, (Figure 3).

3. <u>January 20, Wednesday through January 23, Saturday</u>

The flooding tides of the high-high ranged from 5.2 to 6.0 while the low-high flood tides ranged from 3.4 to 4.0.

Thus, the oil was deposited on the upper zones of the reef from the flooding tides of January 19-23, with the heaviest deposition of oil

coming on the reef January 19 and 20, Tuesday and Wednesday. Figure 3, on page 13, is a map of Duxbury Reef areas indicating the locations where the Bunker C oil was deposited, covering a great percentage of the higher tidal zone outcroppings (from plus 3 to 6) of the reef including the high tidal berm against the mesa's cliff. Where the oil touched the reef, the blanketing on the rocks was not uniform (Figure 4), but deposited mainly in blotches. The locations on Duxbury Reef receiving the most oil were on the windward side of the high berm rocks of Area A and the mussel beds of Area C (Figure 2).

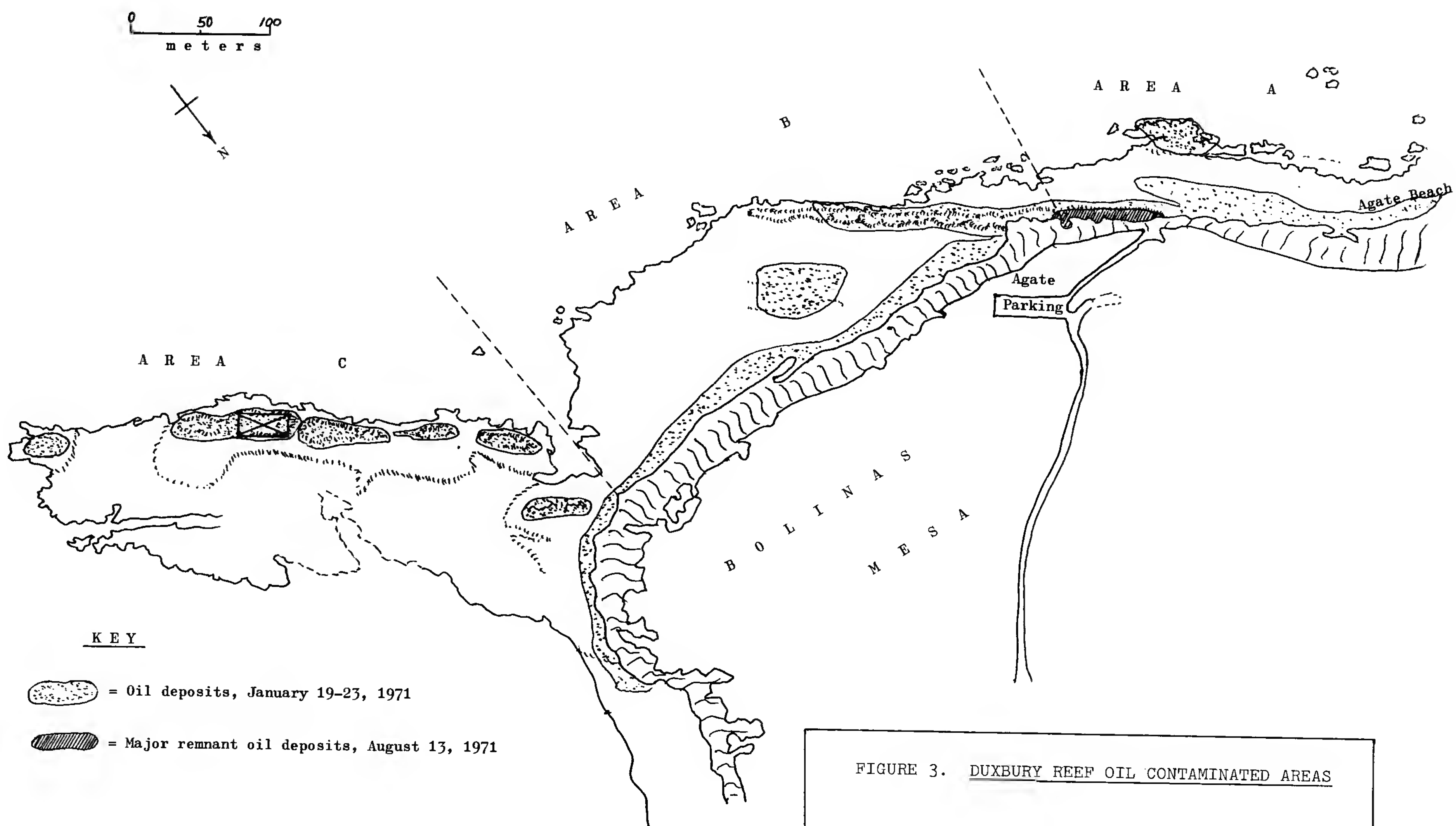


FIGURE 3. DUXBURY REEF OIL CONTAMINATED AREAS

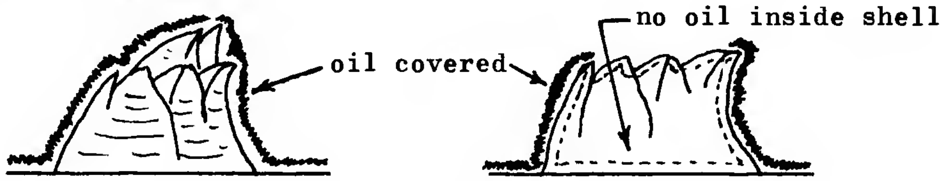
Figure 4. Duxbury Reef, Area A. High-tide berm rocks with oil.

V. SAUSALITO DATA AND FINDINGS

Between the years 1960 to 1965, intertidal transects were studied in the Seal Rock Statue area of Sausalito. From 1960 through 1963, the intertidal rocks teemed with the sea slugs, Anisodoris nobilis and Hermissenda crassicornis; the octopus; the bay mussel, Mytilus edulis; the rock oyster, Pododesmus macroschisma; bryozoans, Bugula spp.; tunicates; and the crabs, Pachygrapsus crassipes and Hemigrapsus nudus. Even the deep water midshipman fish, Porichthys notatus, congregated in great number, averaging 4 per square meter, to lay masses of pea-sized yellow eggs beneath the low tidal rocks. Beginning in 1965, with the surrounding waters becoming more opaque, this lush habitat began to change, with many of the above species starting to decrease in density. Finally in 1967-69, a widening of the Bridgeway road adjacent to the Seal Rock area was undertaken; the gentle sloping intertidal zone area was consequently filled with other rocks hauled in for the construction; marine life had to re-establish itself.

On the morning of January 18, 1971, after learning of the oil spill, I went down to the Seal Rock area at 8:00 A.M. to survey the damage. The exposed rocks at the seal statue were covered with oil. In the former transect area the oil was so thick in spots that no barnacles could be observed under the cover of the oil, but their coated shells could be felt under the pressure of my fingers. In some rocky areas which had no oil coating, living barnacles could be observed. By this time, the tide was flooding quite high, so my observation of the shore crabs, Pachygrapsus crassipes, was limited to the area from the mid-intertidal rocks to the high intertidal rocks. Of the first 100 shore crabs counted, 58 were dead or near dead from the oil and 37 with various degrees of oil on their bodies were scrambling over the rocks. Only 5 living crabs had no oil on their bodies. If I had been asked to offer a prognosis on the fate of the remaining 42 live crabs, I would have

predicted that all of them would be dead within a few days from being smothered in the web of the thick oil. Transect studies were delayed until the oil was sufficiently eroded away to permit the counting of dead barnacles. Dead barnacles counted included whole organisms, intact with carina and rostrum coated with oil, and empty shells with oil covering the outer shell, but none on the inside.



Dead acorn barnacle, organism intact

Dead acorn barnacle, empty shell

Although present in the transects, empty shells with oil inside the shell were not counted as dead from the oil spill. Likewise, barnacle base scars were also omitted from transect counts because of the indeterminate age of these cement scars, indicating that these mortalities may have occurred before the oil spill.

The post-oil study in Sausalito involved two transects, both ten meters long. The oil-contaminated transect was at Seal Rock Statue in Sausalito, approximately where the previous transect existed prior to the widening of Bridgeway Road; observation here was recorded on May 15, 1971. The no-oil transect is located at Fort Baker in Marin County, almost directly under the northern section of the Golden Gate Bridge; observation here was recorded on July 23, 1971.

The comparison of just one group of marine animals, the acorn barnacles, Balanus glandula and Chthamalus dalli, showed remarkable differences between these transects.

The Sausalito transect (Figure 5) is comparable to the Ft. Baker transect, each having protected bay shorelines. The comparison of the two

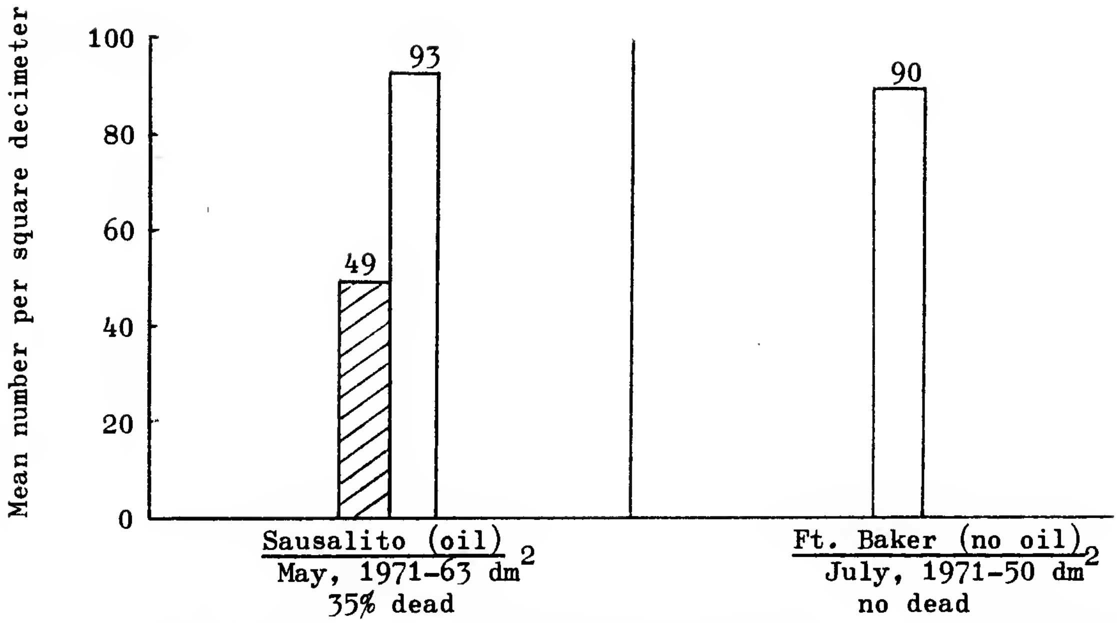


Figure 5. Comparison of barnacles, Balanus glandula and Chthamalus dalli, for transects in Sausalito (oil) and Ft. Baker (no oil)

dead   live

transects revealed the following (Appendix 5):

1. The living populations of barnacles at both Sausalito and Ft. Baker were almost identical in density, about 90-93 barnacles per square decimeter. On the Fort Baker transect, no dead barnacles were counted in the sample, although dead were observed in other areas adjacent to the sample quadrat frame.
2. The Sausalito transect, with scattered blotches of oil over its intertidal rocks, had an average of 49.3 dead barnacles per square decimeter, which represents 35% of of the barnacles counted. The ratio of dead barnacles to live barnacles was 1:2.
3. At Sausalito 2,672 barnacles were counted with oil on their shells; 97% of these were dead.

4. At Sausalito 3,102 dead barnacles were counted; 1,025 (33%) of these were whole animals in their shells, and 2,077 (67%) were empty shells.

A comparison of the sample square decimeters with varying degrees of oil on the rocky surfaces is presented below:

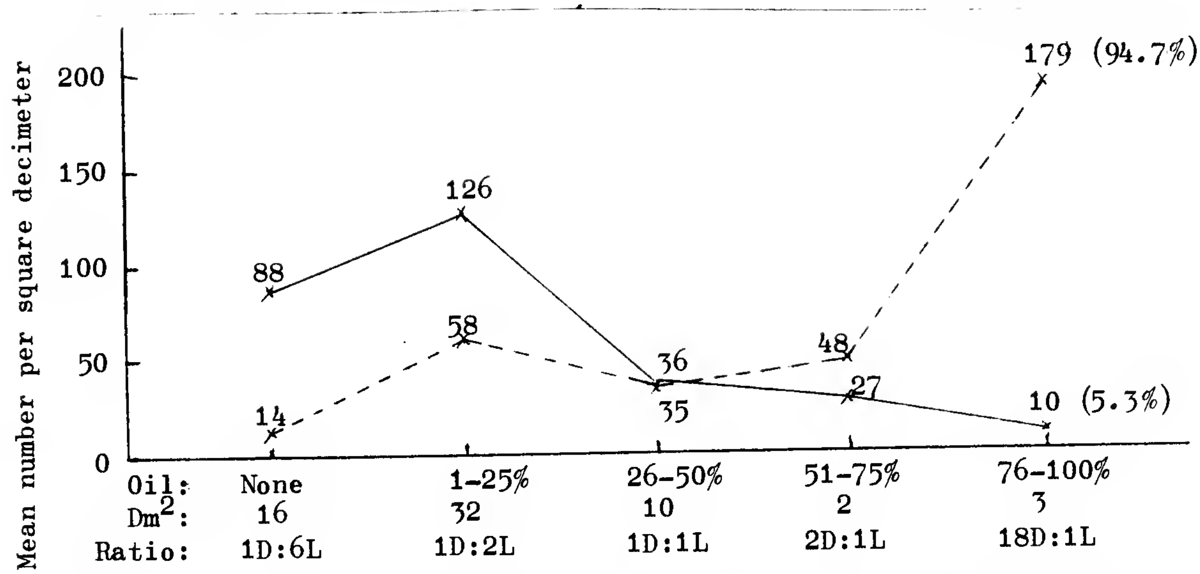


Figure 6. Comparison of square decimeters of Sausalito transect

——— live barnacles

– – – dead barnacles

The number of live barnacles per square decimeter decreased drastically as the coverage by oil increased. The curve in Figure 6 illustrates that living barnacles on 0-25% oil coated surfaces averaged 88 to 126 live barnacles per square decimeter, whereas 76-100% oil coated surfaces averaged only 10 live barnacles. Dead barnacles with oil on their shells were counted in square decimeters where apparently the oil had eroded away.

With my assumption that the barnacle distribution in this area is fairly uniform and a sampling mean of 49 dead barnacles per square decimeter, 50,000 dead barnacles was estimated for the 10-square-meter Sausalito transect. The 95% confidence interval for the population mean of dead barnacles

ranges from 36 to 62. The Sausalito Bridgeway Road walk area encompasses approximately 1,000 square meters, with a barnacle density and residual oil coverage similar to that of the transect (76-100%). For the intertidal rocks in this walk area then, I would extrapolate a conservative total of 3.6 million acorn barnacles smothered by oil based on the lowest point of the confidence interval, 36 dead per square decimeter (Appendix 5).

VI. STINSON BEACH DATA AND FINDINGS

Since June of 1965, we have been sampling Stinson Beach area at Boyle's sand fence near Calle Del Sierra. The transect line is nearly 100 meters long with square meter samples taken every 10th meter on the line for a total of nine square meters in the sampling.

In Figure 7 below, the total number of organisms in this transect at Stinson Beach has declined during the three major sampling dates of July 1965, February 1970, and April 1971, with no change for the remaining three-month period through July 1971 (Appendix 6):

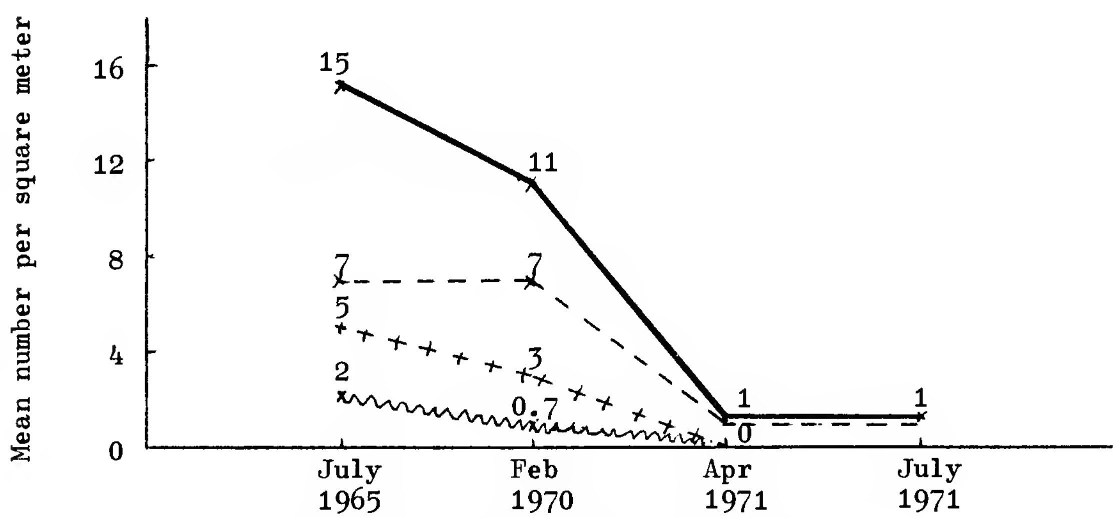


Figure 7. Major species, Stinson Beach transect

- - - *Emerita analoga*, the mole or sand crab
+ + + *Nepthys californiensis*, the sand worm
Orchestoidea californiana, the upper beach hopper
all three species combined

During the oil spill cleanup of Stinson Beach Standard Oil reported that their mechanical graders disrupted the upper six inches of the sandy beach. These upper six inches contain a large proportion of our three studied species (Figure 7); if there were any dead organisms, they were probably removed with the debris picked up by the graders.

With statistical testing, we find there was no significant difference between the population mean of the three species combined for

July, 1965, and February, 1970. However, there was a significant difference in the population mean between February, 1970 and April, 1971 (Appendix 6). The decline of species may be attributed equally to the oil pollution, to the upheaval of sand by the mechanical graders and lifters, and even to the shift of sand from the annual winter storm waves. A comparison of a Drakes Beach transect located near the Interpretative Visitor Center for approximately the same time period revealed that there was also a similar decline in the same species (Appendix 6); Drakes Beach was not contamined by the oil spill. Between April and August of 1971 I recorded an increase of three feet of sand over the Drakes Beach transect site which may account for the low count of organisms. Stinson Beach may have had a similar increase in sand; however, I am not convinced the low 1971 counts in April and July at this transect were due to this. All these circumstances at our Stinson Beach transect prevent me from using the data to attribute a definitive loss of marine organisms to the oil spill. Although no reliable death totals can be extrapolated for the entire beach, I have estimated that approximately 10,000 of the studied species died in our ten-square-meter transect (Appendix 15).

VII. DUXBURY REEF FINDINGS

A. GENERAL REEF OBSERVATIONS

1. The major amount of oil deposited on Duxbury Reef was carried in by the flooding tidal currents between January 19 and 22. The reef areas with the most oil were the major mussel bed of Area C and the high berm rocks of Area A (Figure 3).

2. Observations were made immediately after the spill to assess the loss of marine life. It was not possible to count the dead organisms amidst the conglomerate of oil-tar, straw, and general reef debris--this massive mess made it impossible to begin post-oil transect counts immediately although the attempt was made. Transect studies were delayed until April, although continued visual monitoring of the reef was carried on in the interim to observe gross changes.

3. No visual evidence of a major kill of marine life was observed on the reef for the period, January-April, 1971. However, we observed thousands of dead limpets and barnacles covered with oil on the high berm rocks of Area A. I was fearful for the immediate kill of the vast mussel beds that were inundated with oil. This kill did not materialize. The major noticeable deficit was the lack of the striped shore crabs, Pachygrapsus crassipes, on the berm sections of Areas A and B. On December 9, 1970, this same berm was teeming with this shore crab, scurrying from crevice to crevice. In the four days following the oil spill, I counted only a total of 5 live crabs in the entire berm section of Area A. We looked in the tidal debris for dead crab bodies, but only 42 were counted for a period of two months. In pre-oil days, this area would be "crawling" with these decapods. Hundreds or thousands

of the upper reef shore crabs are obviously missing.

4. Duxbury Reef Transects and Charts

A total of 33 pre-oil and post-oil transects were employed on Duxbury Reef (Appendix 7). Of these, 26 were established before the spill. Only the oil-related transects will be discussed here.

B. DUXBURY REEF BERM FINDINGS

The Duxbury Reef berm in Area A (Figure 3) was severely covered with oil, with a 50% to 75% oil coverage on the rocks (Figure 4). The major organisms in this high tidal section are: *Acmaea spp.*, limpets; *Littorina spp.*, periwinkle snails; *Balanus sp.* and *Chthamalus spp.*, acorn barnacles. The transect studies in this berm area date back to November, 1964. In the comparative transect studies of *Acmaea spp.* and *Littorina planaxis* there is at least a 45% decrease in the live count of these species for the April, 1971, transect count (Figure 8), with the mean number per square meter dropping from $29/m^2$ to $16/m^2$ (Appendix 8).

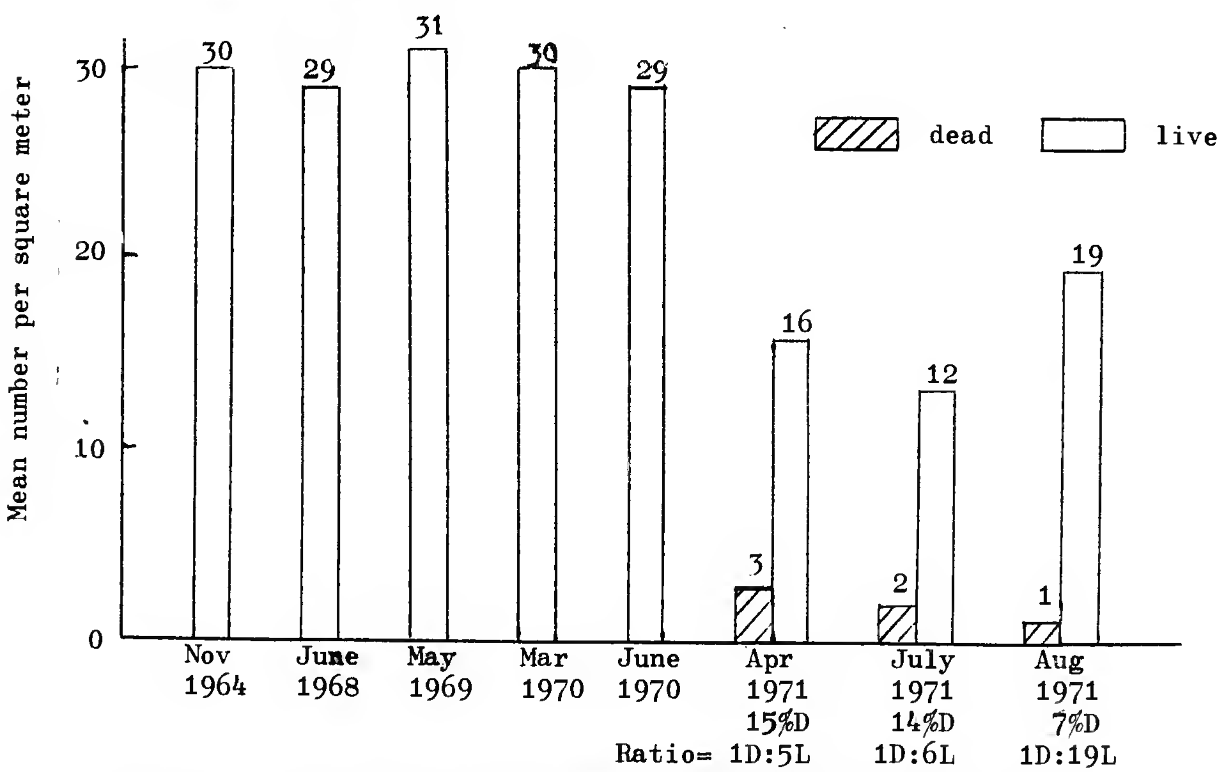


Figure 8. Comparative Studies of Acmaea spp. and Littorina planaxis, per square meter, for Berm A-8,9

Figure 9. Duxbury Reef Berm Area, illustrating limpet "scars" from oil-killed limpets which eventually dropped off the rock habitat.

As noted previously in Figure 8, there were no dead limpets counted prior to April, 1971. After the oil spill, the April, 1971 count showed 3 dead limpets per square meter for the berm transects. Obviously as wave erosion of the oil continues, fewer scars will be counted on these exposed high berm rocks.

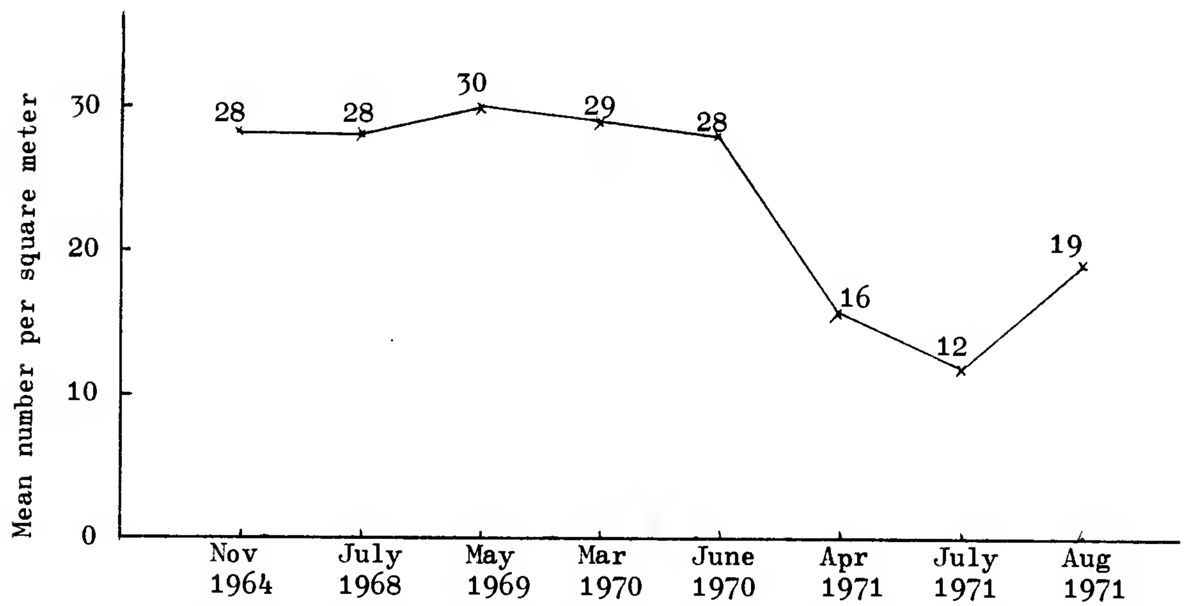


Figure 10. Live Acmaea spp. per square meter for Duxbury Reef, Berm A-8,9

The living limpets in the berm area show a 1964-1970 stability, then a decrease after the oil spill, from $28/m^2$ in June, 1970 to $16/m^2$ in April, 1971. The density of living limpets increased in August, 1971, though not enough to regain pre-oil status.

In April, 1971, an additional 10 square meters sampling (Transect A-10) was added to the study because of the heavily oiled condition of these rocks.

Figure 11, with the live and dead means of limpets per square meter for the combined berm transects A-8, 9, 10, shows a similar August, 1971 increase in live counts.

Limpets which died from smothering by the oil dropped off the rocky

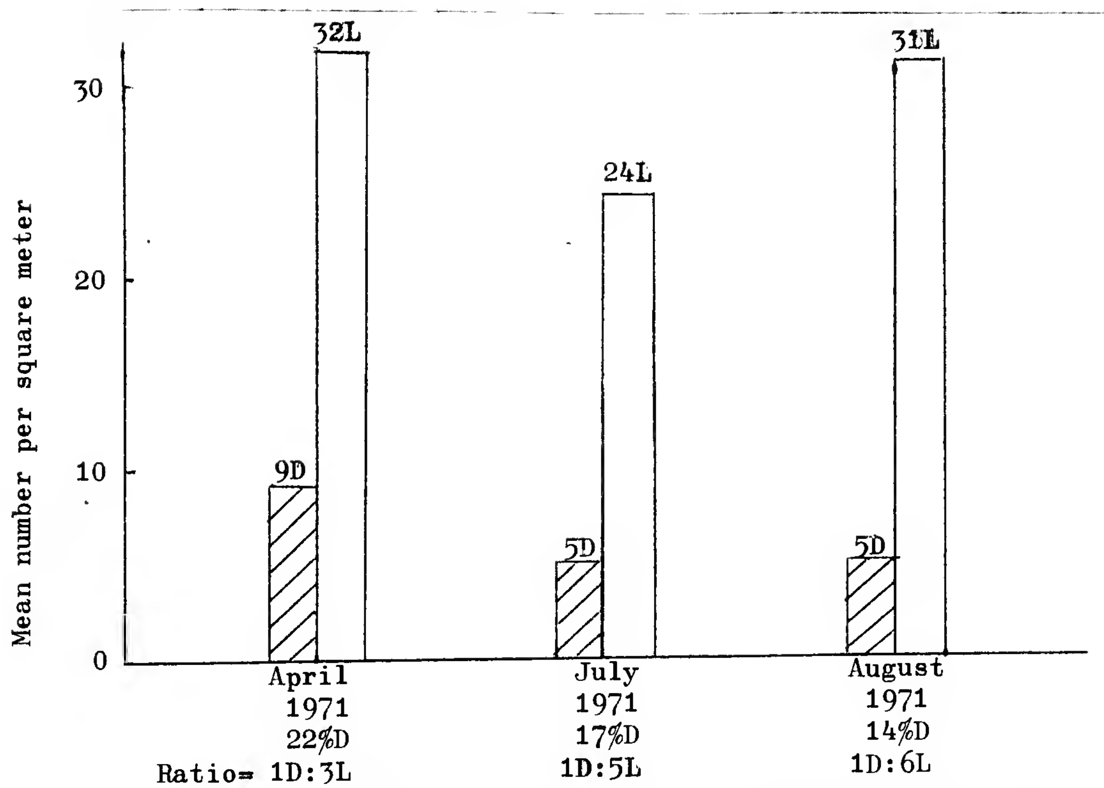


Figure 11. Acmaea spp. live and dead, per square meter, for Berm A-8,9,10

= dead = live

surface, leaving a "scar" or bare spot. The counting of dead limpets included the dead shells still glued to the rocks by oil and straw and the scars left when the shells dropped off (Figure 9). As wave action eroded the oil, the dead count decreased from 9 per square meter in April, 1971, to 5 per square meter in August, 1971.

Using the April, 1971 dead count of 9 per square meter, we may extrapolate the total number of limpets killed by oil in this berm section. Area A berm is approximately 75 meters long; a strip one meter wide running the length of the berm was hit with oil, resulting in an average of 25-50% residual oil deposit per square meter. We can estimate at least 675 limpets were exterminated in this particular 75-square-meter section of the reef.

For a number of years, I have been counting a small population of the grey periwinkle, Littorina planaxis, in this berm section. The numbers were quite steady with little variation up through December 9, 1970 (Figure 12). Immediately after the oil spill, January 23, I could not find one snail of this species. However, the April, 1971 transect count numbered two (one with oil on its shell), then a count of 5 for July, and finally back down to one in August. There is no question in my mind that the sudden decrease in Littorina planaxis is due to the heavy amount of oil which hit this berm area.

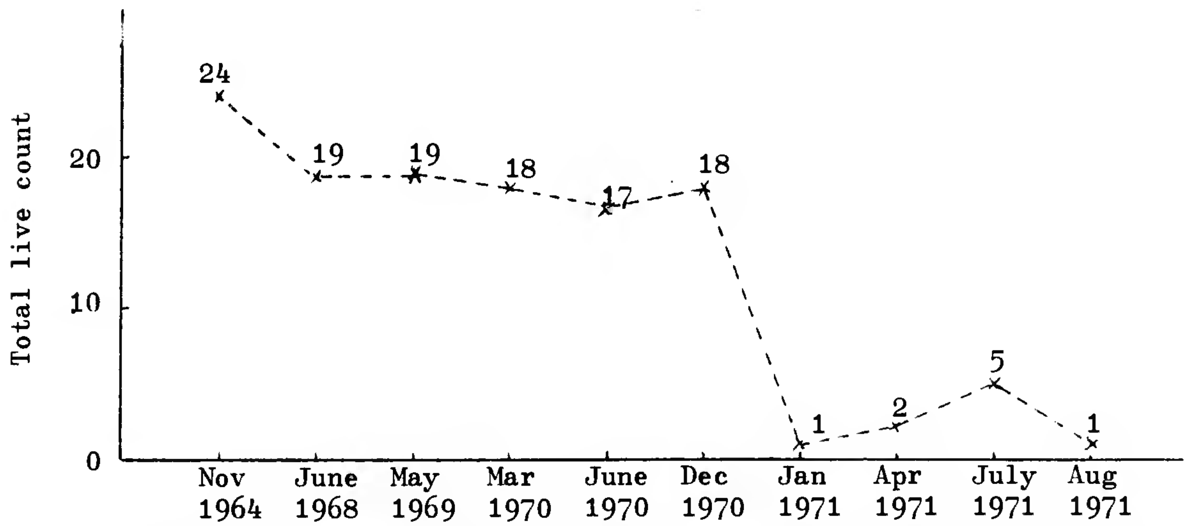


Figure 12. Total transect count of Littorina planaxis for Berm A-8,9

The barnacle sampling on the berm illustrated a similar trend in the ratio of dead to live as seen in the Sausalito transect (Figure 6). The berm ratio shows that the greater the amount of oil on the rocks, the higher the numbers will be of dead barnacles to living barnacles. Figure 13 shows there was an average of 88 dead barnacles in square decimeters with 75% or more oil, compared to only 4 live barnacles.

An extrapolation for the total number of dead barnacles in this berm strip of 75 square meters would be 37,500 dead based on the sample mean of 5 dead barnacles per square decimeter (Appendix 15).

Thus, a conservative estimate of at least 675 limpets and 37,500 barnacles may have been smothered in this Duxbury berm area from the oil spill deposits.

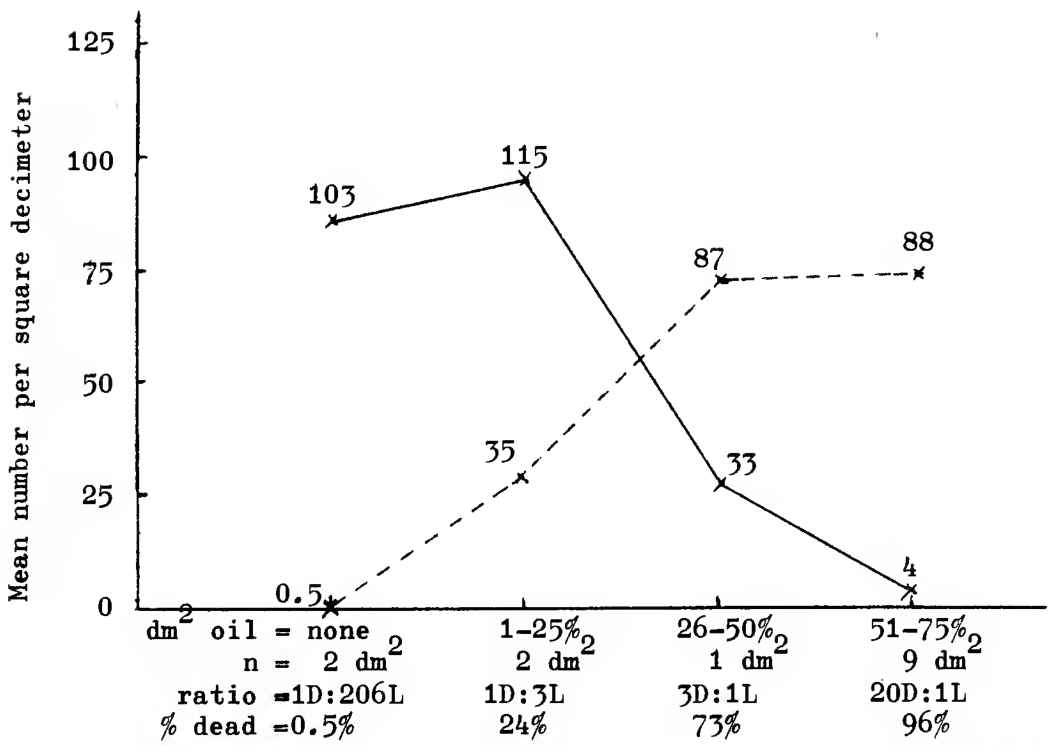


Figure 13. Ratio of dead and live barnacles according to the amount of oil on the rocky surfaces of square decimeter plots for Berm A-10, April, 1971

——— = live - - - = dead

Thousands of the small periwinkle snail, Littorina scutulata, occupy the berm area, some 500 per square meter. Approximately 8% of these snails were recorded as dead and "glued" to the rocks by the Bunker C tar, in a April, 1971 count on transect A-10. The 95% confidence interval for the population mean for dead ranged from 14 to 26 per square meter. Employing the low of 14 dead per square meter to provide a conservative figure, we can estimate at least a total of 1,050 dead Littorina scutulata for this berm area.

The presence of young and adult limpets in the oiled sections of the berm may indicate a trend toward normal densities. Figure 10 showed that the August, 1971 count of limpets per square meter was up to 19 for transects A-8, 9. Although limpets do move around in their search of algal food, and these counts may reflect limpet movement, over the years I have found that limpets are relatively stable in their numbers in a particular site. In past years I have marked limpet shells on numerous occasions in this area and the sample shells remain relatively in the same location for years. Some of these same limpets are recorded in the stable curve between November, 1964 to June, 1970.

Furthermore, in Figure 14, the data illustrates that the living limpets, Acmaea spp., and the periwinkle snail, Littorina scutulata, are returning and living on top of the oil. Approximately 0.1% of the living limpets were on top of the oil in April, and 14% in August. Note that in the high recruitment month of July, 39% of the living limpets were on top of the oil.

The same picture existed with the snail, L. scutulata, the percentage climbing from 6% in April to 44% in August, 1971.

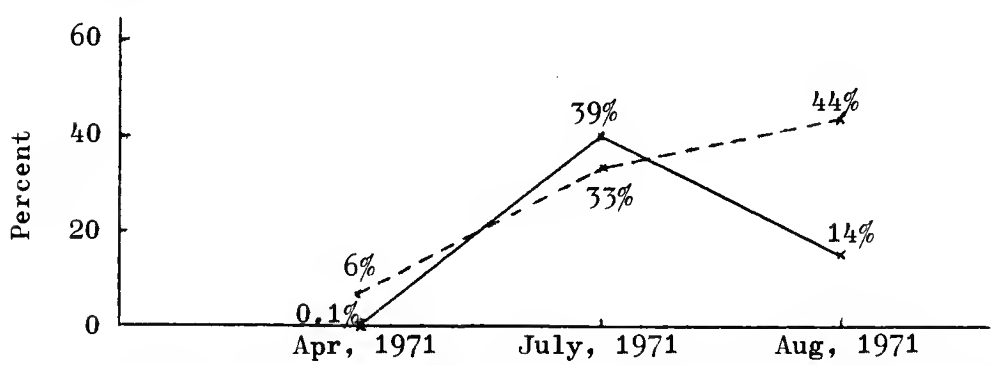


Figure 14. Percentage of live Acmaea spp. and Littorina scutulata on top of oil, square meter and decimeter data for Berm A-8, 9, 10.

——— % of live Acmaea spp. on top of oil
– – – % of live Littorina sp. on top of oil

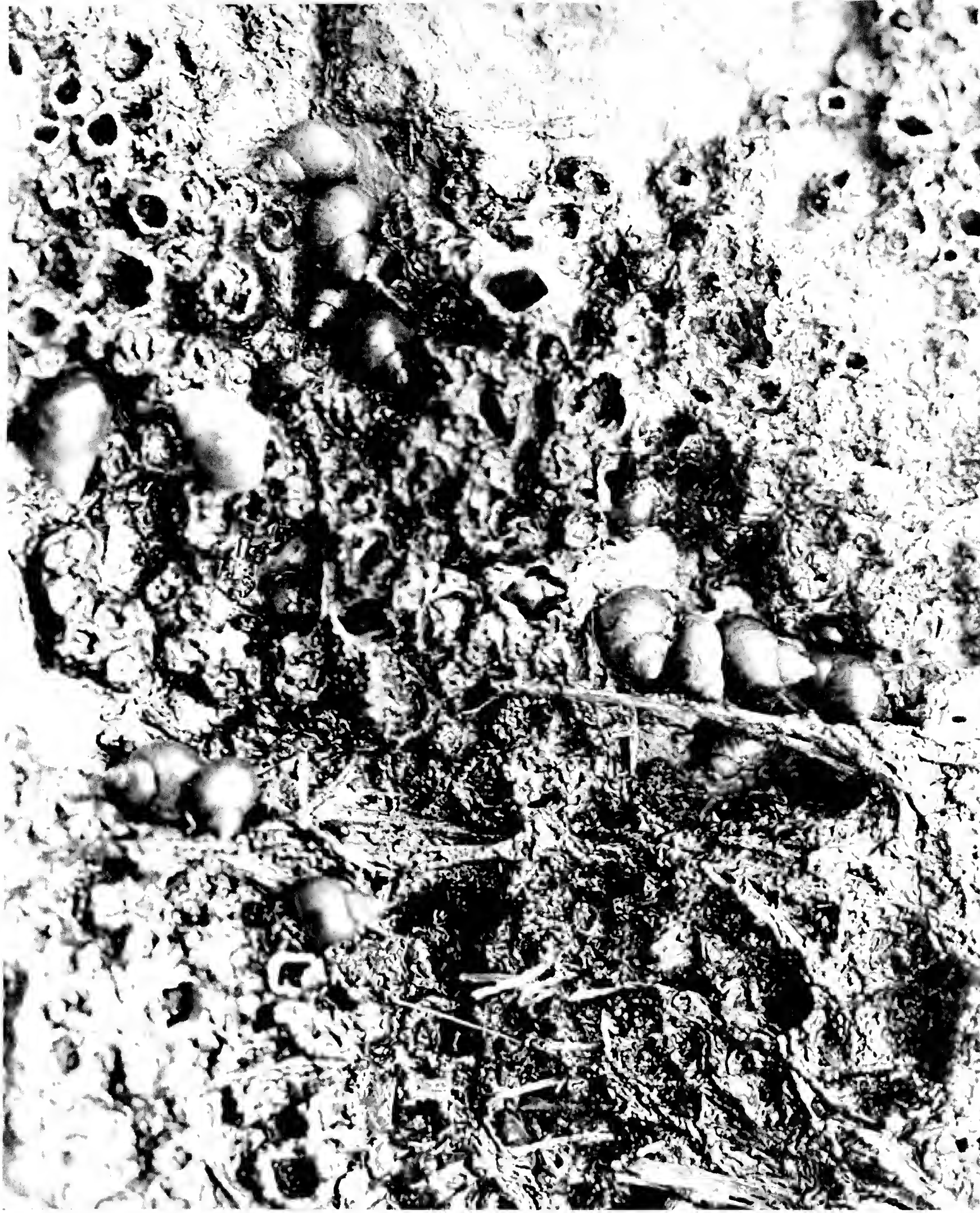


Figure 15. Living Littorina scutulata on top of oil deposits. August, 1971
Notice dead barnacles from oil suffocation.

C. DUXBURY REEF MUSSEL BED TRANSECTS

In the Area C section of Duxbury are vast beds of the mussel, *Mytilus californianus* (Figure 2). From a previous 1968 measurement of Duxbury Reef (9), I would estimate that over one million mussels presently inhabit this section of the Area C reef, with the mussels ranging from a half inch to six inches in length. On January 19, 1971, Tuesday afternoon, with a flooding 3.3 late afternoon tide, these mussel beds were blanketed by a heavy coat of Bunker C oil. At least 50% to 75% of each mussel bed was heavily soaked with oil. A single square meter sampling of these mussel beds in 1968 yielded a total count of 4,000 mussels, crabs, worms, barnacles, limpets, snails, etc., which live in association with each other. Therefore, there must have been several million marine organisms, in my opinion, similarly doused with the oil.

The staff of the Bolinas Marine Station feared for these large populations of fauna which form such a significant portion of the marine life of the reef. I observed that the mussels which were soaked with oil were all still alive. A close surveillance was kept on the entire reef's mussel beds for the succeeding months. We expected these mussels to die within a few days, on the basis of Sanders' testimony (2) of massive die-offs, including bivalves, which occurred within one to two days after the No. 2 fuel oil spill off West Falmouth, Massachusetts, on September 16, 1969. Our studies, which are still continuing, show that a large immediate die-off did not occur with the Bunker C. Obviously, the Massachusetts oil spill conditions were different from that of the San Francisco oil spill.

In Figure 16, the mean of dead mussels per square meter is given, with the peak die-off occurring just previous to the April 1, 1971 count.

All dead mussels, at 12 dead per square meter, had oil on their shells.

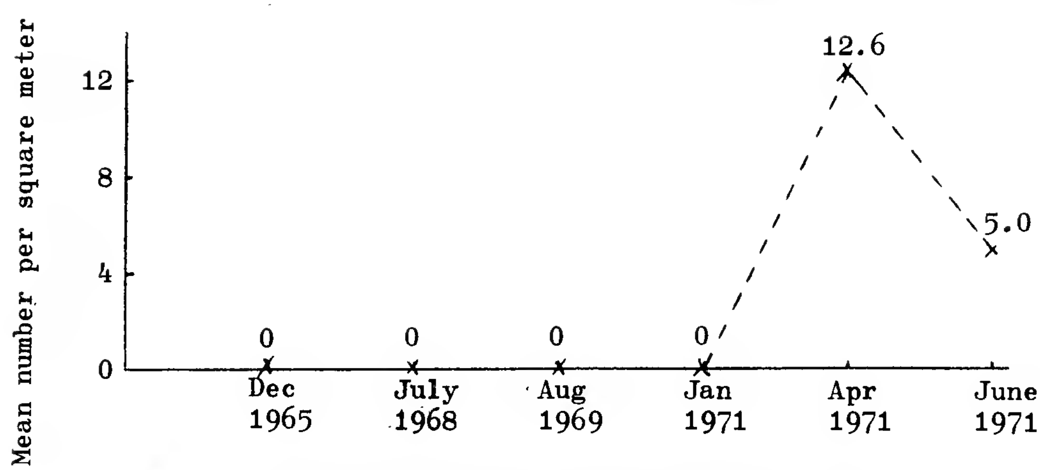


Figure 16. Dead Mytilus californianus per square meter, Duxbury Reef, Area C transect

The cause of the two-month delay in the die-off from the oil spill is not discernible to me at this time. The water temperature between January and February ranged from 12° to 16°C, and the air temperature fluctuated between 13°C in January down to 12°C in April. My studies, with use of the thermister probes inside the shells of mussels with oil and those without oil, were inconclusive; the water temperature inside the shells fluctuated greatly from shell to shell regardless of whether the outside surface had oil or not. Our study leads me to conclude that in this Area C mussel bed transect with a population of some 157,000 mussels, about 3,000 mussels died, a die-off of about 2%, based on January and April sample counts.

In succeeding months, waves eroded away the dead shells and the lower counts for June, 1971, indicate the remnant dead mussels. No new die-offs were recorded for the remaining oil-covered mussels.

Throughout the months of February to April, we pried up mussel bed shells to observe the density of organisms living under the mussel beds. To conserve marine organisms, I thought it best not to scrape off a

square meter patch as is the custom in counting such populations (Castenholz, 1967)(12). From my observations, there was little effect of oil on these thousands of organisms living under the mussel beds. Apparently the canopy of mussels afforded a protective roof for these organisms.

The population of the goose barnacle, Pollicipes polymerus, which also lives in association with the mussels did suffer some damage. Figure 17 shows that the mean number per square meter for this barnacle dropped from 31 in August, 1969, to 24 in April, 1971. In recording this decrease of goose barnacles per square meter, we observed that all the dead barnacles were covered with oil and presumably were smothered.

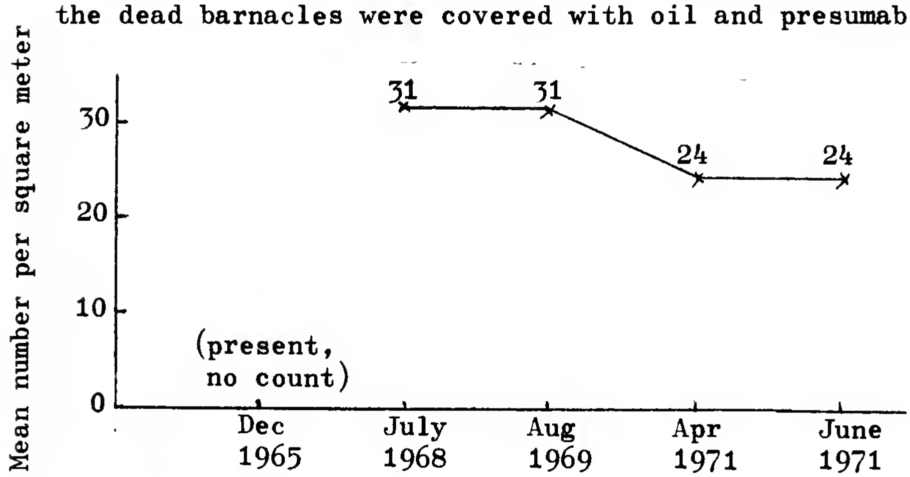


Figure 17. Live Pollicipes polymerus per square meter, Duxbury Reef, Area C mussel bed transect

Another study on the mussel bed concerned the acorn barnacle, Balanus glandula, on the shells of the mussels. Figure 18 shows that the greater the amount of residual oil on the surface of the mussels, the higher the ratio of dead barnacles to the live barnacles. For instance, on square meters where 51% to 75% of the mussels had oil on their shells, there were about 26 dead barnacles to 10 living barnacles per square decimeter, or 72% dead barnacles. Of all barnacles counted, 51% were dead; all dead barnacles were oil covered.

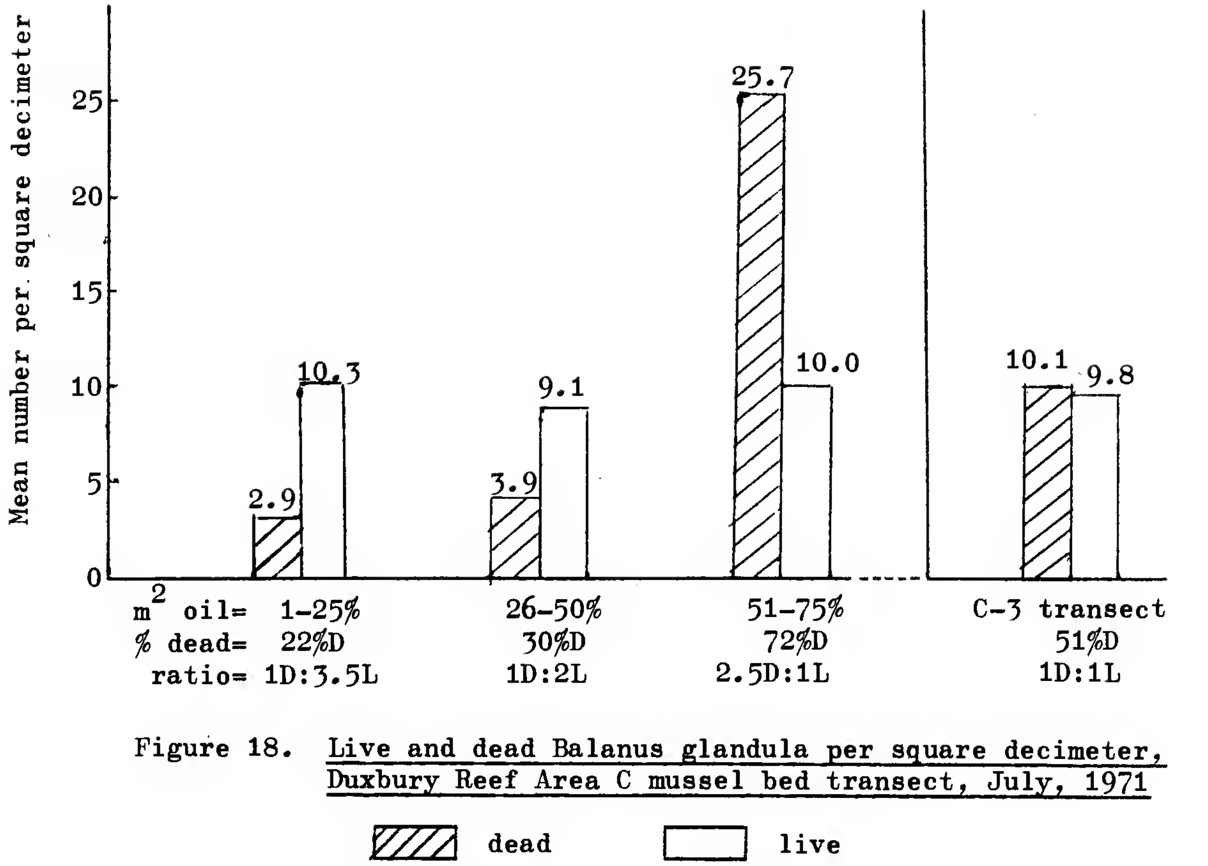


Figure 18. Live and dead Balanus glandula per square decimeter, Duxbury Reef Area C mussel bed transect, July, 1971

The living mussels remained relatively stable over the years, from December, 1965, through June, 1971. The counts averaged from 7.5 to 8.8 per square decimeter in this time period with a slight dip in population density presumably due to the January, 1971 oil spill.

A heretofore unobserved occurrence was noted in July, 1971, on the mussel beds. A thick growth of algae appeared on mussels and rocks which were covered with oil, Figure 19. The sequence of events follows:

	Mussels with oil on shell	Mussels without oil on shell
January-June, 1971	no algae	no algae
July, 1971	Algae: Chaetomorpha aerea (thick growth) and Enteromorpha intestinalis	no Chaetomorpha or Enteromorpha
August, 1971	Algae: Porphyra perforata (thick growth)	Algae: Porphyra (light growth)

Figure 19. Thick growth of Chaetomorpha aerea on mussel shells with oil on their surfaces.

The photograph (Figure 19) illustrates the thick growth of the filamentous green algae, Chaetomorpha aerea, on mussel shells coated with oil. In my fourteen years of observing on Duxbury Reef, I have not, before July, 1971, seen such an abundance of algae. Shells without oil had no C. aerea on their shells. In previous years I had found this algae on Bolinas Lagoon wharf pilings and had always associated this growth of algae with the amount of organic sewage polluting the Bolinas Lagoon waters. The peak growth of the two green algae occurred between July 9-22, 1971. At that time we recorded:

5,280 filaments of C. aerea per square centimeter
590 filaments of E. intestinalis per square centimeter

Needless to say, the density of these green algal growths was very substantial. The growth of the red algae, Porphyra perforata, is common to mussel beds during the summer months.

I have speculated that the Bunker C oil on the mussels shells provides an ideal substrate for C. aerea. I do not believe that this algal growth will affect the population of mussels although a long term study will be carried on in this reef section. Consultation with marine botanists will take place over the succeeding months.

The population of mussels and all of its association organisms as of this publication is one of apparent good health. The algae have all disappeared from the shells of the mussels and the density of this marine mollusk is stable at approximately 8 mussels per square decimeter.

D. OTHER MAJOR MARINE ORGANISM TRANSECTS

1. Tegula funebralis, the Black Turban Snail

The habitat of *Tegula funebralis* is generally the Zone 2 protected reef sections within the Duxbury Reef areas. From the map (Figure 3) I have estimated approximately 25% of the *T. funebralis* habitats were contaminated with oil in various degrees, from 25% to 75% coverage, with oil being concentrated in Areas A and B.

Transect studies from June, 1969, to August, 1971, gave evidence that this snail moves around the rocky reef. Transect studies in past years indicate a fairly stable per square meter count of the snail throughout the reef. However, the April, 1971 count dropped from previous means of more than 30 to a low of 15 per square meter (Figure 20).

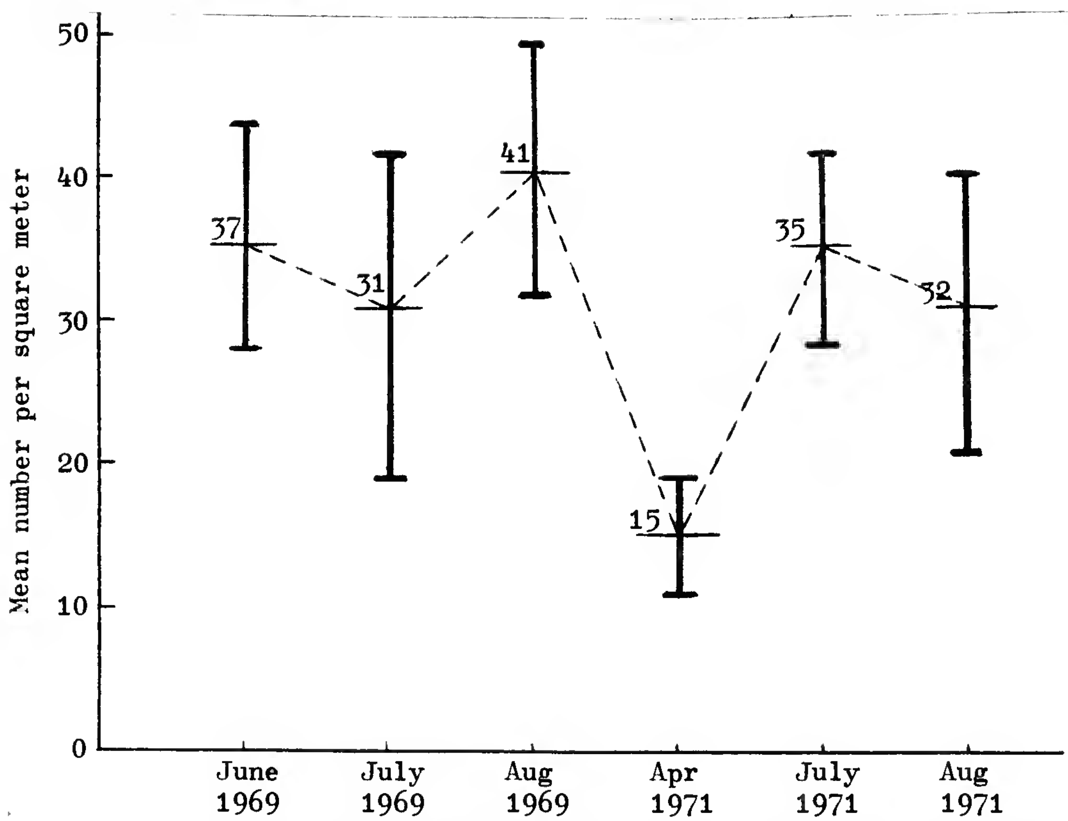


Figure 20. Confidence intervals for *Tegula funebralis*

I = 95% confidence interval for population mean

+ = sample mean

The test statistics (Appendix 10) indicate that there is a significant difference between the mean number per square meter of April, 1971, and the means of August, 1969, and July, 1971.

Although I am inclined to believe that the oil spill had an influence on the death rate of *T. funebralis* in the early months, I am not convinced that the low April, 1971 count can be entirely attributed to oil pollution. Also, I feel the early spring and seasonal movements of this snail had an influence on this count. Algae production on the reef is not great in April and together with at least a 25% oil covered rocky reef area, food for this snail may not have been readily available. Comparison of 1969 and 1971 summer counts indicate stability of organisms on the reef flats. Until we repeat the transect counts for April, 1972, we will have to hold off judgment as to the reasons for the low April, 1971 counts.

In Figure 21, comparison is made for the presence of this snail between transects with no oil and transects with oil. Notice that the April, 1971 counts show a drop for both no-oil and oil transects.

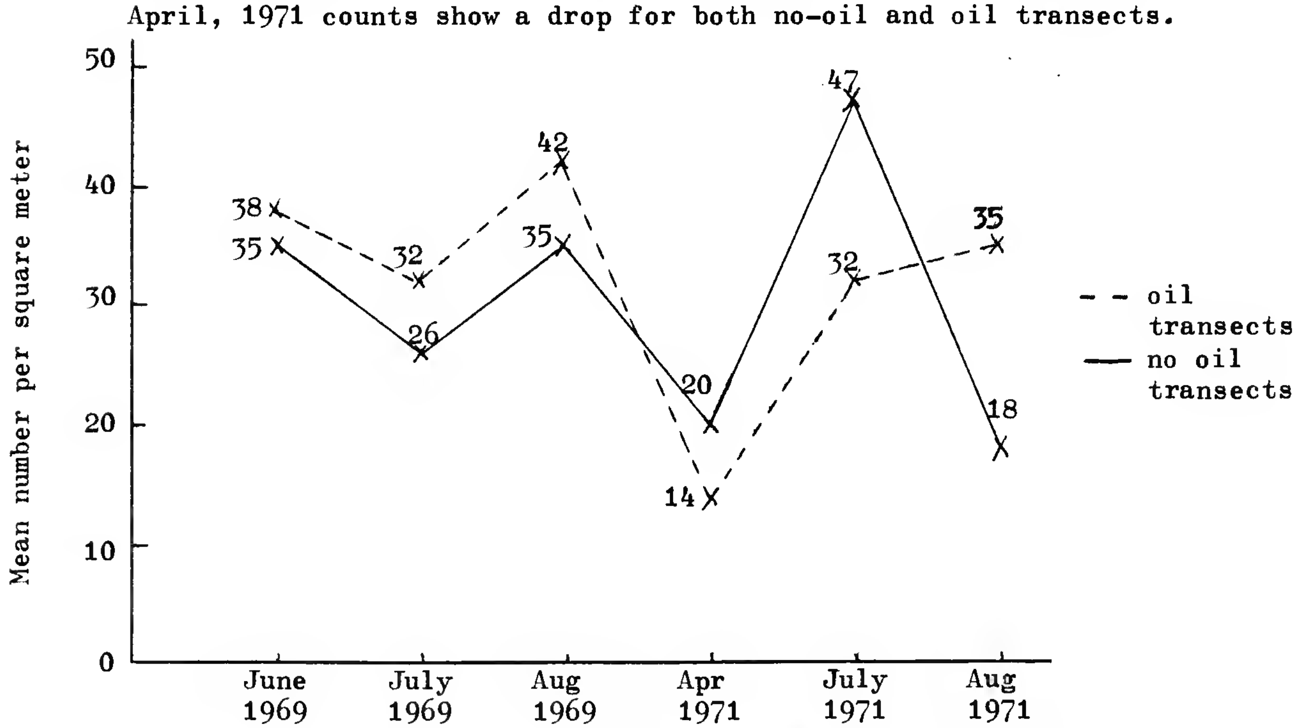


Figure 21. Comparison of no-oil transects with oil transects for *Tegula funebralis*

In another T. funebralis comparison (Figure 22) between transects of 1-50% oil coverage and transects of 51-100% oil coverage, both counts dropped in April, 1971. However, the transects with 51-100% oil coverage showed that the T. funebralis did not occupy these oil covered rocks in the summer months of July-August, 1971. These turban snails seem to be avoiding the more heavily oil-covered rocks, favoring the rocks with 1-50% oil coverage.

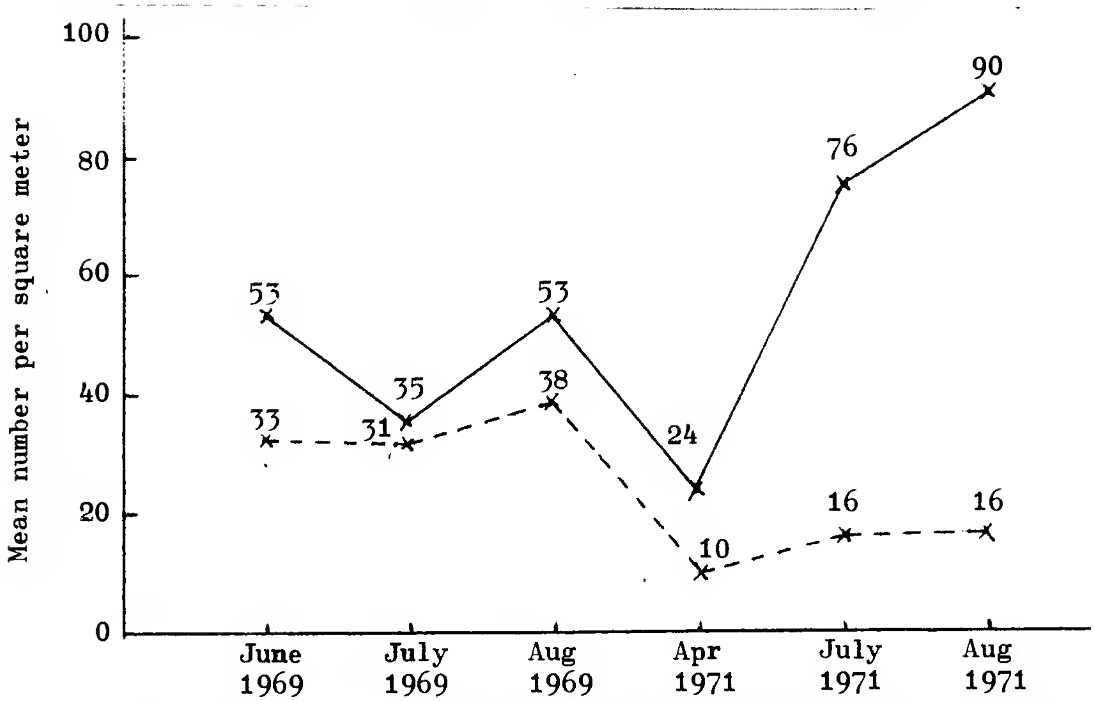


Figure 22. Comparison of 1-50% oil transects with 51-100% oil transects for Tegula funebralis

——— = 1-50% oil transects

– – – = 51-100% oil transects

Mr. Craig Hansen of the Bolinas Marine Station conducted an oil exposure experiment on T. funebralis by use of the tidal tank described earlier. The tests showed that T. funebralis is indeed hardy and of the 26 snails placed in a Bunker C tank, none died after a test period of four weeks (Appendix 13).

2. Pisaster ochraceus, Ochre Starfish

A yearly summary of a Zone 4 low intertidal transect in Area C labeled "starfish corner" indicated low per square meter counts immediately after the spill (Figure 23). As in the Tegula funebralis observation, the low counts of 21, 17, and 19 starfish in the months of January to March, 1971, probably cannot be attributed to the oil spill.

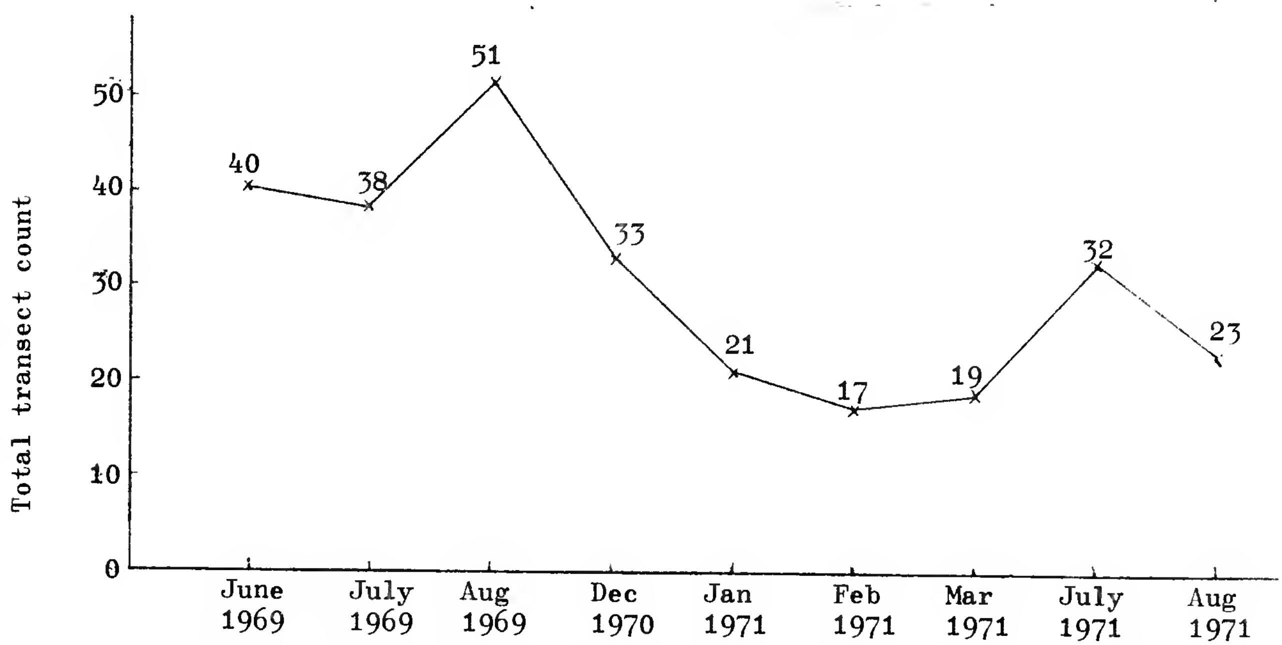


Figure 23. Total live Pisaster ochraceus, Duxbury Reef, C-4 transect

The specific transect site, which is quite low in the intertidal zone, had less than 25% oil. Although the starfish feed on the nearby beds of mussels, some of which were coated with oil, an examination of the transect's starfish in February, 1971, showed no oil on these echinoderms. Furthermore, examination of the loose mussel shells scattered around these starfish showed none of the shells had oil. Perhaps these starfish will eat only mussels whose shells have no oil.

3. Other Organisms

The population of the sea urchins, Strongylocentrotus purpuratus, were basically not affected by the spill because the oil settled on higher intertidal rocks. Counts from past years remained stable.

The transect counts for the oil limpet, Lottia gigantea, and the black sea slug, Hermaeina smithi, have been decreasing since February of 1959. This downward trend is probably due to other causes, including predation by man, rather than the oil spill.

The shore crabs, Pachygrapsus crassipes and Hemigrapsus nudus, as mentioned in the discussion on Area A berm, are presently not as abundant on the reef as before the spill. The transect method for counting crabs always gives questionable results because of the mobility of these organisms. Mr. Craig Hansen reported a 40% loss of crabs from oil contamination during the testing period at the Bolinas Marine Station. Under these conditions, it appears that the oil greatly interferes with the mouth appendages of the crabs, resulting in the crab's death after a period of 10 days.

Throughout the reef, the rock boring piddocks and related clams showed little change in numbers; again, the majority of these animals are found at a lower intertidal elevation than the mussel bed community. Likewise, the red rock crab, Cancer antennarius, and the various sea anemone and chiton populations also did not show any drop in populations.

Since 1967, I have tagged 12 red abalones, Haliotis rufescens, in subtidal transects on the reef (Figure 2, at X-12). In ten subtidal dives between January and August, 1971, we have not seen one of these tagged abalones (Appendix 9). However, recovery of our

tagged abalones from Bolinas to Point Reyes has not been successful. In my opinion, there is as yet no established relationship between our missing tagged abalones and the oil spill. In all of our diving operations around the reef, we have not observed any remnant or traces of subtidal oil. These subtidal studies will continue.

E. MARINE PLANTS

1. Marine Algae

Two species of marine algae received heavy coats of Bunker C oil during the week of January 18-21, 1971. These were *Endocladia muricata* and *Gigartina cristata*. In transects which contained both species, the 1971 spring and summer production of each plant appeared to be normal in comparison to previous years. No biomass studies of drying and weighing were conducted, my visual observation being the criterion of judgment.

Moreover, parts of Duxbury's protected reef flats were coated with up to 75% oil on some square meters in January. During January, I raised some questions among fellow biologists as to whether the coming spring and summer months would show normal growth of the algae, *Halosaccion glandiforme* and *Iridaea flaccidum*. This summer's *I. flaccidum* production, I would say, appeared normal, but the *H. glandiforme* growth was extremely thick. In the protected reef flats of Areas A, B, and C, the bulb-like red algae grew as I have never seen before.

Similarly, as previously discussed in relation to the mussel beds, the filamentous green algae, *Chaetomorpha aerea*, appeared in a dense growth on the mussel shells that had oil on their surfaces.

2. Marine Surf Grass

The single species of marine surf grass found throughout the

entire reef is Phyllospadix scouleri. On one transect tidepool in Area C, near the mussel bed transect, I have recorded the growth of the marine plants since 1959. This tidepool's surf grass was saturated with oil. A slight die-off at the outer tips of the blades was recorded in February, but growth of the surf grass during the remaining spring and into the summer months appeared normal. At another surf grass section of Area A, at Stake 2 transect, the P. scouleri growth up to August, 1971, appeared to be heavier than in previous years.

F. VISITOR COLLECTING ON THE REEF

In the summer of 1969, I conducted an extensive study on the activities of visitors to Duxbury Reef (13). The major finding in that study was that man's hunting and collecting activities can severely alter marine environment within a short number of years. Furthermore, with conservation education introduced to visitors, a behavioral change can take place which will reduce man's hunting and collecting of marine organisms. The conservation education which began that summer, 1969, has been and continues to be maintained by the Bolinas Marine Station staff. With contributions from the report on that study, Duxbury Reef was finally added to the list of California's marine reserve sanctuaries in 1971. With Duxbury Reef as a marine reserve and state regulations prohibiting the collecting of marine organisms from the reef, a study was conducted during the months of June to August, 1971, to see if there were still individuals making live marine collections and possibly contributing to the changes in populations.

In Appendix 11, the data revealed that only 12.8% of the visitors collected in summer, 1971, as compared to 32.7% in 1969 for a five-week period when conservation education was first introduced. There was

significantly less collecting in 1971 than in 1969. The irony of the marine reserve status is that people still collect, but this predation can be further reduced with better educational and enforcement activities. At any rate, it does not appear that the significant drop in the numbers of marine organisms can be attributed to collecting by visitors.

G. <u>SUMMARY OF DUXBURY REEF MARINE ORGANISM TRANSECTS</u>

This summary involves thirteen baseline transects established before the spill; the Area A berm transects and Area C mussel bed transect are <u>not</u> included. Studies of these 13 transects showed that the post-oil counts were significantly different from the pre-oil counts (Appendix 12). Figure 24 charts the mean number per square meter.

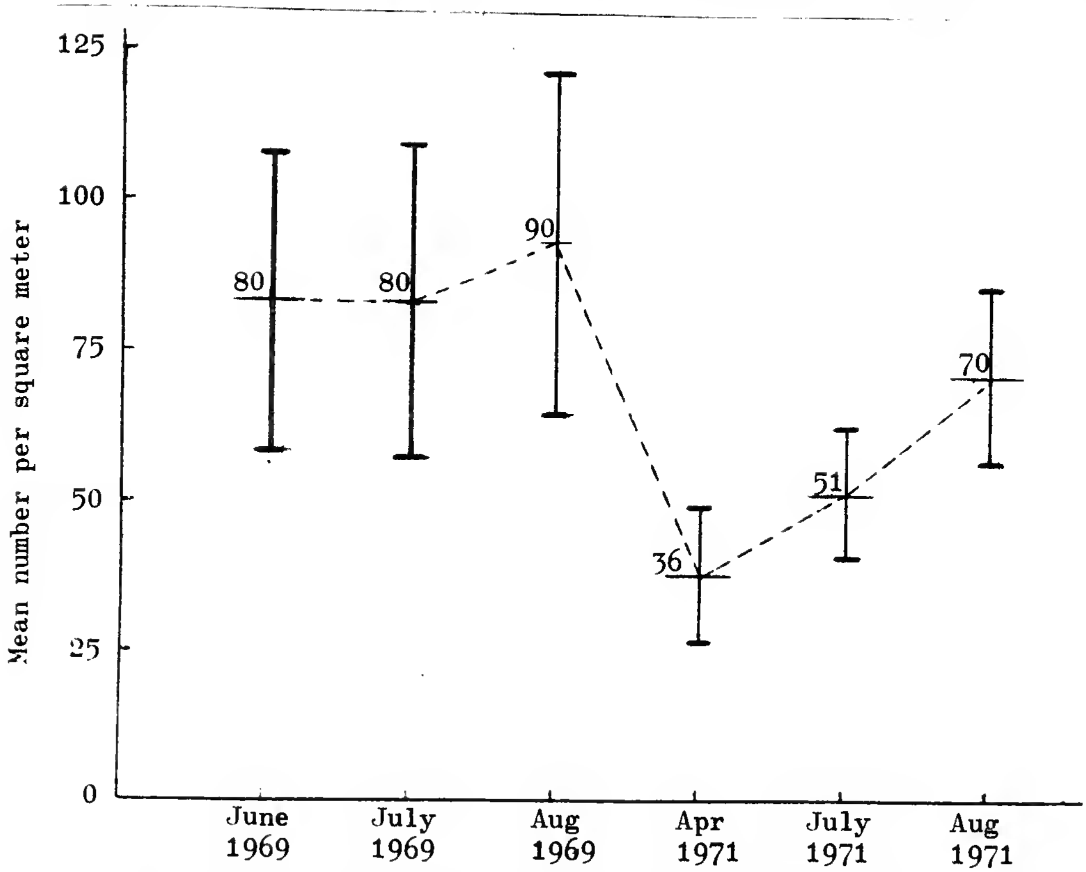


Figure 24. <u>Confidence intervals for live counts, all species, 13 transects</u>

I = 95% confidence interval for population mean

+ = sample mean

The test statistics (Appendix 12) indicated that we should reject the hypothesis that the post-oil counts were not significantly different from the pre-oil counts; there was a severe drop in the overall population of marine organisms on the reef. The April, 1971 mean of 36 represented a 60% decrease from the August, 1969 mean of 90. Notice that Figure 24 is similar to Figure 20, the studies on Tegula funebralis, the black turban snail.

If we were to remove the significance of T. funebralis from the overall transect chart, would we still observe a decrease in marine organisms per square meter over the entire Duxbury Reef?

Figure 25 reflects the mean number of all species combined, excluding T. funebralis.

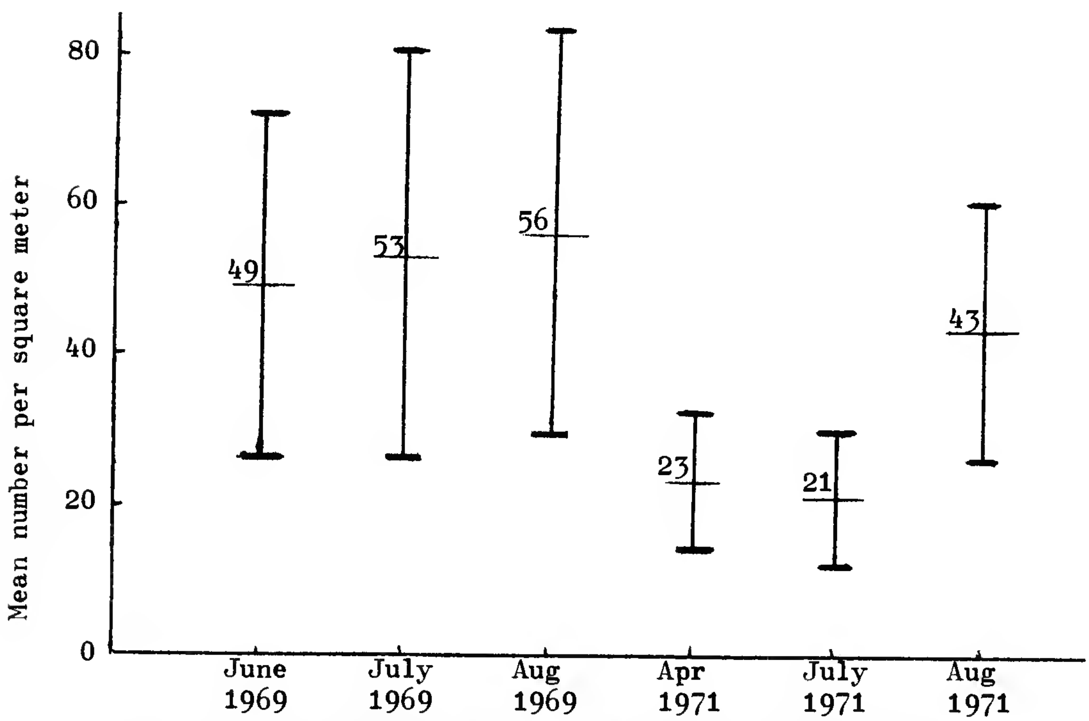


Figure 25. Confidence intervals for live counts, all species except Tegula funebralis, 13 transects

I = 95% confidence interval for population mean

+ = sample mean

The pre-oil spill transect means per square meter were still higher than the post-oil means, Figure 25. There was a significant difference between the pre-oil and post-oil counts, a marked decrease in marine live after the spill as seen in the April and July, 1971 counts.

Two assumptions, either singly or collectively, can be made about the April, 1971 slump in marine populations at Duxbury. First, the oil spill contributed to the decline of species numbers illustrated in Figures 24 and 25. Secondly, the slump may have been caused by seasonal fluctuations of the species, due to such causes as migration, low productivity, and storms and waves. However, when we compare the previous spring transect counts of May, 1969, and March, 1970, to the spring of 1971 (Figures 8, 10, and 12), we find that the populations of the limpets, *Acmaea spp.*, and periwinkle snail, *Littorina planaxis*, were quite stable in their densities. In other words, the month of April, 1971, which had a mild weather pattern, showed an unusual downward trend in marine life density on the reef.

To illustrate that natural deaths occurred, Figure 26 shows that there were 2.3 dead acorn barnacles per square decimeter on two transects which had no oil. The adjacent graph for six transects with 51-100% oil coverage, including the berm and mussel bed transects, shows an average of 7.2 dead acorn barnacles per square decimeter. On a few decimeters with oil, it was difficult to determine if there had been oil on some of the empty shells, so all empty shells in these few samples were counted. The predatory conditions vary among these Duxbury Reef transects. We can assume that there were deaths due to natural causes, but on the basis of our reef studies over the years, the significant drop in marine life during the spring of 1971 was primarily due to the oil spill contamination.

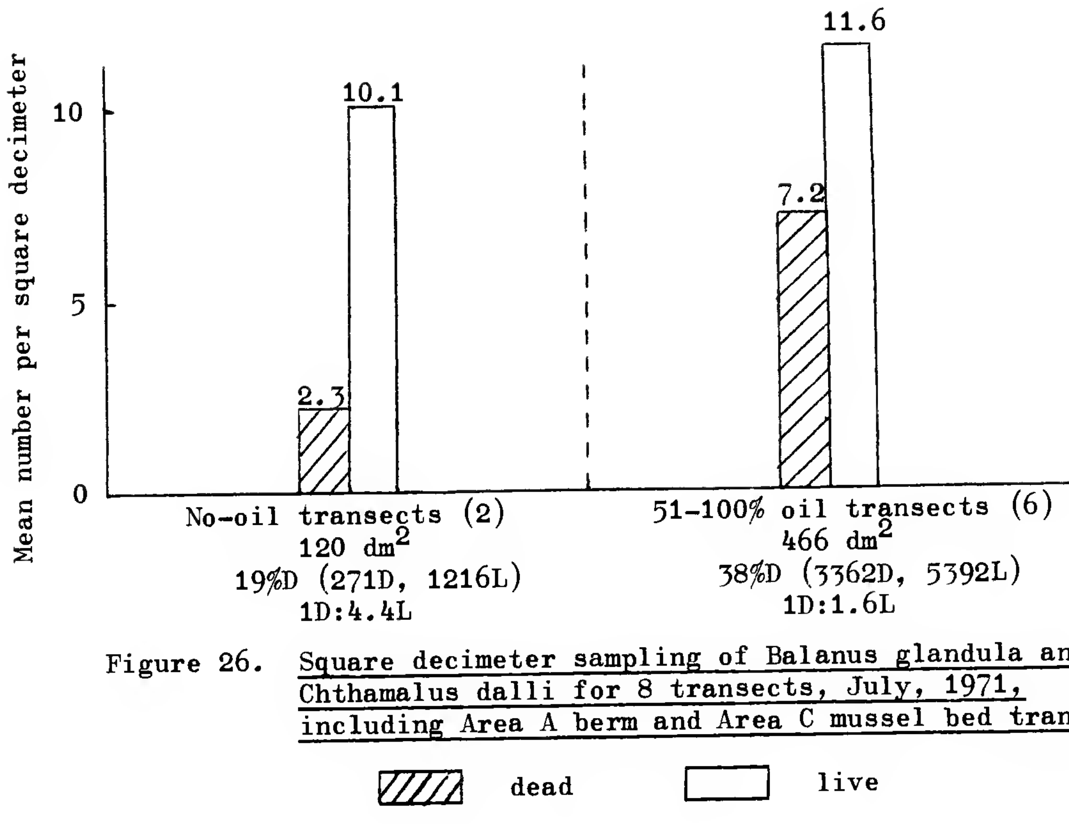


Figure 26. Square decimeter sampling of Balanus glandula and Chthamalus dalli for 8 transects, July, 1971, including Area A berm and Area C mussel bed transects

Throughout the Duxbury Reef observations, the August, 1971 transects illustrated new growth and recruitment among the majority of marine species (Figures 24 and 25, Appendix 12). Statistically, there is no significant difference in the short-term analysis of the density or population means of marine organisms between the August, 1971 counts and the August, 1969 counts, except for the 51-100% oil transects (Appendix 12). Among the prominent species, mussels, black turban snails, periwinkle snails, limpets, and sea anemones, many young juveniles were seen as evidence of good recruitment among the reef populations.

H. SUMMARY, LABORATORY OIL TEST TANKS

The oil spill occurred during the early morning hours on January 18, 1971, at the Golden Gate Bridge. About 24-30 hours later, the oil began to be deposited on Duxbury Reef. Our major objective in these laboratory tests was to determine if Bunker C oil, after 30 hours' exposure to current, tides, wind, and evaporation, would be less toxic than Bunker C oil fresh from the containers supplied by the Standard Oil Company.

Mr. Craig Hansen set up a series of test tanks, each with a capacity of twenty gallons. Approximately 50 milliliters of oil were added to each 20-gallon tank, which was the amount of oil needed to cover the exposed water surface. I have estimated that about 50 milliliters, which weigh 39.5 grams at 20°C, occupied about one square decimeter of rock surface on the Duxbury berm and mussel beds.

Three types of tanks were maintained:

Unconditioned tanks = Bunker C oil fresh out of the container
Conditioned tanks = Bunker C oil exposed by tidal action for 30 hours
Control tanks = no oil

Specimens of the marine species which were subjected to the most oil contact on Duxbury Reef were placed in these tanks and data was compiled on their survival-death ratio over a period of four weeks, November 2-30, 1971 (Appendix 13).

The major findings in these laboratory oil tests were:

1. The quantity of Bunker C oil became less dense with each six-hour tidal cycle and with each passing day. Much of the oil adhered to the sides of the tank and the rocks and organisms within the tank, while the remainder floated on the water surface. Very little sank to the bottom of the tanks.

2. _Tegula funebralis_, the mobile black turban snail, did not suffer any mortality in either the conditioned or the unconditioned oil tanks.

3. Two out of five striped shore crabs, _P. crassipes_, died in the conditioned oil tank.

4. All the mussels, _M. californianus_, were still alive after four weeks in the control and oil exposure tanks.

5. A very significant death rate occurred in the goose barnacle, _P. polymerus_, in the unconditioned oil tank where Bunker C was poured into the tank without benefit of a 30-hour tidal cycling period. Approximately 89% of the barnacles died in the unconditioned oil while only 44% died in the conditioned oil. Surprisingly, our control tank had a barnacle mortality of 57%. The only conclusion we can draw is that _P. polymerus_ does not survive well in any of our marine tanks, and death comes quite easily in the unconditioned oil which has more volatile toxic compounds than the conditioned oil.

6. The control tanks, with no oil, had a death rate of 31% for all organisms, probably due to handling and transferring the organsism from their natural habitat to the tanks. In contrast to the control tanks, the conditioned oil tanks had an overall death rate of 44% and the unconditioned, 48%.

In summary, this short-term laboratory study of Bunker C oil's effect on marine organisms generally supports the field observations of higher death rate among the barnacles and limpets and lower death rate among the snails. The long-term effects of the oil on the animals need further study.

VIII. CONCLUSIONS

The January 18, 1971 San Francisco oil spill affected selected marine organisms throughout the area. The Bunker C oil was thrown onto baseline transects which had been established before the accident. The studies in this report confirm the major hypothesis formulated in this publication--that smothering was by far the most important factor in the marine organism die-off due to contact with Bunker C oil. The decrease in marine organisms in the transect areas was not due to storm conditions, natural predators, nor zealous collecting by man, but was attributable mainly to the contamination of these organisms by the oil. The major conclusions of this report are as follows:

A. Sausalito Area

The beaches of this boat-oriented community within the confines of San Francisco Bay received much oil, swept onto its rocky shores by the early morning tides of January 18, 1971. One major kill of marine organisms involved the acorn barnacles. I estimated that some 3.6 million barnacles may have perished along the Bridgeway Road breakwater. The other heavy kill was among the crab population, although no estimate of number of dead was made (Appendix 15).

The marine life in the rocky intertidal area was changing <u>before</u> the oil spill. Species of sea slugs, rock oysters, mussels, marine snails, and fish which occurred there in 1967-1967 have disappeared from the Bridgeway rocky intertidal zones. There is no question in my mind that other polluting factors may have attributed to the decline of these organisms in this area.

The barnacle, limpet, and crab populations may return in time, barring no other catastrophe.

B. Stinson Beach

The pre-oil transects at Stinson Beach (Figure 7) showed a slight decline in species before the oil spill. The post-oil spill counts showed a further decrease in the major marine species of the mole crab, sand worm, and beach hopper. No estimate of deaths due to oil can be made for this beach although these sands were heavily saturated with oil, straw and debris from the spill. The mechanical graders and lifters removing oil from the beach probably contributed to organism destruction. The populations of marine life on this beach are significantly low in comparison to the previous year. Continual studies through the spring of 1972 may provide better data as to the status of these beach populations.

C. Duxbury Reef

The Bunker C oil came onto the reef January 19-23, 1971, heavily contaminating the mussel beds and high berm rocks. While the baseline transects were not established in anticipation of an oil spill, they did provide a framework upon which to conduct our post-oil spill study. The major part of this report has concentrated on the events that occurred on Duxbury Reef:

1. Large amounts of oil were deposited in the berm and mussel bed sections. As suggested by our laboratory studies, a 30-hour tidal aeration process probably accounted for much of the evaporation of volatile components in the oil. Most of the animals died as a result of being smothered under a coat of oil.
2. Acorn barnacles and limpets suffered the highest mortality on the berm parts of the reef. In a 75-square meter section of the berm, I have estimated that some 37,500 barnacles and 675 limpets died from being smothered by the oil. On decimeter samples that had

51-75% oil coverage, approximately 96% of the barnacles on these rocks were found dead from the oil contaminants. Overall statistics for the reef illustrated that the higher the percentage of a square meter or decimeter was covered with oil, the higher the kill among sessile and sedentary marine organisms.

3. Mobile marine life, such as crabs and snails, probably suffered less mortality than the sedentary animals. Counting shore crabs in square meter transects has always been somewhat unreliable; these fast moving animals can be in and out of crevices within a blink of the eye. Comparing the numbers of crabs observed before and after the spill, I would definitely state that the shore crab population after the spill is significantly less than before the spill. The Area A berm rocks had a November, 1971 count of only 35 crabs. In previous years, I can recall seeing hundreds of crabs in this same area.
4. The mortality counts of the marine snails (periwinkles and black turbans) with oil on their shells were very low, except for the berm transects, even though the drop in population in April, 1971, from the previous count of August, 1969, showed significant difference (Figure 20). Such a difference may have too many variables to attribute the decline to the oil spill.
5. The vast mussel beds in the Area C section were heavily covered with Bunker C oil, and I truly felt that these mollusks would suffer enormous losses. As it turned out, the mussel deaths from oil is estimated at about 12,000 out of a population well over a million mussels occupying 2,000 square meters; approximately half of that area--1,000 square meters-- was affected by the oil.
6. Some of the marine algae in the higher intertidal zones were

covered by the oil. Likwise in some areas of the reef, the surf grass was covered with oil. There was a bloom of the green algae, _Chaetomorpha aerea_, on the mussel beds. Furthermore, the encrusting brown algae, _Ralfsia pacifica_, seems to be heavier than usual. Perhaps the algal blooms reflect that there is a lower population of grazers, such as _Tegula funebralis_, on the reef.

7. The estimated total dead for Duxbury Reef is 1,058,840, mostly barnacles, based on the sample means (Appendix 15). The overall decrease in all marine life on oil transects was a 60% drop in live organisms (Figure 25 and Appendix 12), comparing pre-oil to post-oil data, August, 1969, to April, 1971.

8. The final and most important question is the status of Duxbury Reef at the present time. The staff of the Bolinas Marine Station concurs with my judgment that the reef, as of December, 1971, appears to be in good health. Any hidden variables of the oil effects will need further observation; however, the visible signs are these:

    a. The oil is disappearing from all reef surfaces. The asphalt-tar substance is being eroded from the Area A berm rocks, as well as the mussel shell surfaces in Area C. Only in crevices, where oil and straw are mixed together, do we find visible evidence of the former heavy presence of oil. Within another year the remnant oil spots should be small indeed. The periwinkle snails, _L. scutulata_, are crawling over the oil as if the oil did not exist. Looking into the oil-straw impact crevices, we have found many aggregations of small specimens of these snails. On November 30, 1971, on a visit to this berm area, I noticed that oil films still exist in the upper tidepool waters;

the oil has been found consistently in these pools throughout the past year, a result of seepage from the remnant oil in the crevices of the berm.

b. The macro-examination of reef populations--the large mussel beds, the numerous marine snails (Tegula funebralis and Littorina scutulata), the limpets--showed that all of these appear to be in good health. Only the acorn barnacle populations on the upper berm rocks where the oil smothered the lives of many of their numbers do we find an absence of recruitment.

In the overall summary of the effects of the oil spill along the coastal shores of Marin County, there was significant kill from the Bunker C oil of about 4.2 million barnacles, limpets, and other organisms, all smothered by the oil (Appendix 15). With the disappearance of oil from the reef rocky surfaces, I am quite pleased with the recovery of marine life in our study areas.

Although my present observations seem favorable, the shadow of the unknown effects of oil still lurks within the environment. To stop our studies now would be a sign of complacency and poor judgment. There could still be marine die-offs from the effects of oil, particularly on the Duxbury Reef mussel beds. There could also be repercussions within the food web of the reef because of oil pollution. On the other hand, the initial good recruitment may continue. There are too many "if's" to close the case on this oil spill.

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APPENDICES - TABLE OF CONTENTS

APPENDIX 1 STUDENT ASSISTANCE IN THE DUXBURY REEF SURVEYS

1955-1968

Lawrence Andrews
Rosamond Day
Dean Glaser
Terrance Gosliner
Dan Orr
Robert Pool
David Seielstad
Paul Sagues
Gary Williams

1969

Albert Blair
Phil Davis
Judy Diamond
Kent Erskine
Don Ferdinand
Peter Forni
Bryan Gaddy
Mark Gmeiner
Anne Hiaring
Robert Johnson
Lynda Kransberger
Stephen Schafer
Lee Shackelford
Cathy Sinclair
Tinsley Stetson
Jackie Strong
Susan Sullivan
David Wills
Paige Wilson
Robert Young

1970

Carolyn Alverson
Kathryn DeMasi
W. J. Edick, Jr.
Christie Fairchild
Stephan Krug
Marc Mitchell
Mark Murray
Greg Myers
Karie O'Brien
Edmund O'Conner
David Toponce
Diane White

1971

George C. Anderson
Sheldon Ball
George Bergman
John Biere
Pat Casey
Robert Dager
Chris Freis
Daniel Gelbaum
Steve Harris
Manuel Ignacio
Karen Luchessa
Tom Measles
Don Melton
Mike Meredith
Anita Myketuk
Andrea Nuessle
Susan Peck
Julius Robinson
Stanley Smith
Lynne Stenzel
Rock Trowbridge
Terry Vetromile
Donald Wright
Carl Zeigler

(In such a list I may have omitted, unintentionally, a few other deserving students- G. Chan)

TRANSECT WORKSHEET - G. Chan
January, 1971

APPENDIX 2

Study Site______________________

Area_____Section_____Channel_____

Transect______Type______________

Other___________________________

____

____

Reference_______________________

Investigator____________________

For the organism count of each species found, give total number alive and total number dead. If any shells have oil, give number with letter S in parentheses, e.g., (7S).

Year_____Date_____Tide/Time__________Water temp.____Other______________

Plot #	Oil?	Species= Algae, other	Organism Count	Size=Avg. mm.	(S=shells with oil)									
			Live	Dead	Size	Live	Dead	Size	Live	Dead	Size	Live	Dead	Size

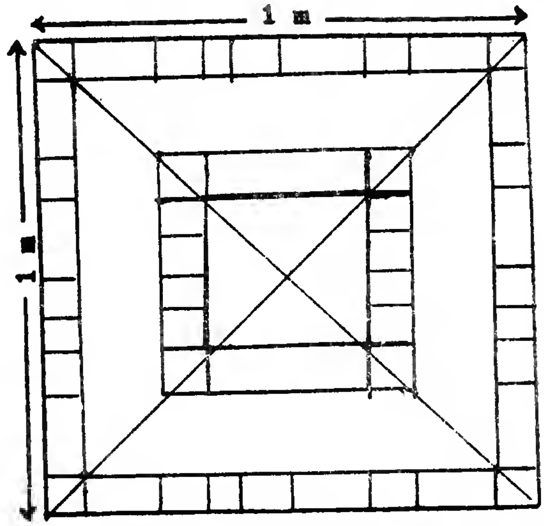
Year_____Date_____Tide/Time__________Water temp.____Other______________

Plot #	Oil?	Species= Algae, other	Organism Count	Size= Avg. mm.	(S=shells with oil)									
			Live	Dead	Size	Live	Dead	Size	Live	Dead	Size	Live	Dead	Size

APPENDIX 2- continued

Berm____

DUXBURY BERM WORKSHEET - G. Chan



Location:

Area____ Section____ Berm____ Plot#____

Other________________________

Log:

	Year	Date	Tide, Time	Other Conditions
1.				
2.				
3.				
4.				

Memo count only: S = shells covered with oil; ST = shells with oil, on top of oil; T = shells with no oil, on top of oil

Place in parentheses (no. of shells covered w oil=S; no. of shells on top of oil=ST, T)

CATEGORY	Acmaea digitalis Total (S -ST T)	Acmaea scabra Total (S -ST T)	Littorina scutulata Total (S -ST T)	Balanus glandula Total (S_2-ST T) ONE DM^2	Other organisms, Changes in oil residue, algal growth
1. Live					
Dead					
Total-m^2					
$\bar{X}$ size and range	mm.	mm.	mm.	mm.	
2. Live					
Dead					
Total-m^2					
$\bar{X}$ size and range	mm.	mm.	mm.	mm.	
3. Live					
Dead					
Total-m^2					
$\bar{X}$ size and range	mm.	mm.	mm.	mm.	
4. Live					
Dead					
Total-m^2					
$\bar{X}$ size and range	mm.	mm.	mm.	mm.	

APPENDIX 3 RESIDUAL OIL ON TRANSECTS

Transect oil was designated according to total number of square meters with oil, in little or much concentration. The same designation was given to individual square meter or decimeter samples to indicate oil coverage in the sample plot.

For a transect with 10 square meters, transect oil was:

N = no square meters had residual oil
+ = 1–25% oil; 1 or 2 square meters with oil
++ =26–51% oil; 3, 4, or 5 square meters with oil
+++ =51–75% oil; 6 or 7 square meters with oil
++++ =76–100% oil; 8, 9, or 10 square meters with oil
NN = transect did not receive oil at all; spill did not reach transect

Transect Oil	Transect
	DUXBURY REEF
	Area A
++++	A-1
+	A-2
++	A-3
N	A-4
++++	A-5
++++	A-6
++++	A-7
++++	A-8
++++	A-9
++++	A-10
N	A-11
++	A-12
	Area B
+++	B-1
++++	B-2
N	B-3
N	B-4
N	B-5
+	B-6
+	B-7
N	B-8
++	B-9

Transect Oil	Transect
	Duxbury Reef (continued)
	Area C
++++	C-1
N	C-2
++++	C-3
+	C-4
+	C-5
+	C-6
++	C-7
+	C-8
N	C-9
N	C-10
++	C-11
N	C-12
	SAUSALITO
++++	SA-1
	FORT BAKER
NN	FB-1
	STINSON BEACH
++++	SB-1 Top 6 inches graded off
	DRAKES BEACH
N	DB-1, 2, 3

APPENDIX 4 STATISTICAL FORMULAE

TERMINOLOGY

Sample refers to the group of individuals directly studied. The sample is but a representative "specimen" or portion, randomly selected, of a much larger total group called the population.

Population, as noted above, refers to the total aggregation of a species of individuals in a statistical study. Population statistics are based on data collected from the study of the sample group.

Mean refers to the average of all measurements.

Proportion refers to the percentage portion (in decimal form) of the sample having a certain characteristic (successes) or NOT having a certain characteristic (failures), e.g., proportion live or proportion dead.

SYMBOLS		For the Sample	For the Population
Mean	$\bar{X}$	$= \frac{\sum x_i}{n} = \frac{\text{sum of all measurements } (x_1 + x_2, \ldots + x_n)}{\text{Number in the sample } (n)}$	μ
Proportion	$\hat{p}$	$= \frac{\text{number of successes}}{\text{number in sample}}$	p
	$\hat{q}$	$= \frac{\text{number of failures}}{\text{number in sample}}$ $\quad \hat{p} + \hat{q} = 1.00$	q
Mean of the Differences	$\bar{d}$	$= \frac{\sum d_i}{n} = \frac{\text{sum of all differences}}{\text{number in sample}}$	d
Variance	s^2	$= \frac{n \sum x_i^2 - (\sum x_i)^2}{n(n-1)}$	σ^2
Standard Deviation	s	$= \sqrt{\text{variance}}$	σ
(subscripts)	o	= pooled or common for two or more samples, such as pooled variance or pooled proportion	

FORMULAE

Data from the sample may be interpreted in terms of the population by use of statistical formulae and tables, Z table for $n \geq 30$, t for $n < 30$.

For Population Mean

The 95% confidence interval is used consistently in this dissertation to determine the interval within which we expect the population mean to be. If, on the basis of repeated sampling, many 95 % confidence intervals for μ are set up, then approximately 95 % of these confidence intervals will actually contain the true mean, μ.

For sample size less than 30: $\alpha = .05$

$$P\left(\bar{X} - t_{\frac{\alpha}{2},n-1} \frac{s}{\sqrt{n}} \leq \mu \leq \bar{X} + t_{\frac{\alpha}{2},n-1} \frac{s}{\sqrt{n}}\right) = 1 - \alpha$$

For sample size equal to or greater than 30: $\alpha = .05$

$$P\left(\bar{X} - Z_{\frac{\alpha}{2}} \frac{s}{\sqrt{n}} \leq \mu \leq \bar{X} + Z_{\frac{\alpha}{2}} \frac{s}{\sqrt{n}}\right) = 1 - \alpha$$

APPENDIX 4 - continued

When comparison is made between two population means or proportions, the data obtained from the two representative samples is used to test the null hypothesis, H_0:

$$H_0: \mu_1 = \mu_2 = \mu_0$$

$$H_1: \mu_1 \neq \mu_2$$

Test statistic Z (formula below) is used to test H_0. if Z is greater than or equal to 1.96 or less than or equal to -1.96, we reject H_0 and accept the alternate hypothesis H_1.

To test for significant difference between two populations, the following test statistic formulas are used:

For Testing Hypotheses

1. Using the mean

Test statistic: $$Z = \frac{\bar{X}_1 - \bar{X}_2 - (\mu_1 - \mu_2)}{\sqrt{\frac{(s_1)^2}{n_1} + \frac{(s_2)^2}{n_2}}}$$

(For sample size less than 30, formula and test statistic with t values and pooled variance was used)

If H_0 is rejected, interval estimate of $\mu_1 - \mu_2$ =

$$\bar{X}_1 - \bar{X}_2 \pm Z_{\frac{\alpha}{2}} \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$$

2. Using the proportion

Test statistic: $$Z = \frac{\hat{p}_1 - \hat{p}_2 - (p_1 - p_2)}{\sqrt{\hat{p}_0 \hat{q}_0 \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

which is distributed as N(0,1) when H_0 is true.

If H_0 is rejected, interval estimate of $p_1 - p_2$=

$$(\hat{p}_1 - \hat{p}_2) - Z_{\frac{\alpha}{2}} \sqrt{\frac{\hat{p}_1\hat{q}_1}{n_1} + \frac{\hat{p}_2\hat{q}_2}{n_2}}$$

The analysis of the transect data consisted mainly of testing for significant difference between the population means of two date counts. Most comparisons were made for the following sets of dates, particularly for Appendices 10 and 12:

June, 1969–July, 1969	April, 1971–July, 1971
July, 1969- Aug, 1969	July, 1971- Aug, 1971
Aug, 1969- Apr, 1971	Aug, 1971- Aug, 1969

APPENDIX 5 SAUSALITO - FORT BAKER DATA

Square decimeter sampling of
Balanus glandula and Chthamalus dalli

	Sausalito transect	Fort Baker transect
	++++ oil	NN oil
	May, 1971	July, 1971
	10 m^2 transect	10 m^2 transect
Number in sample=	63 dm^2	50 dm^2
B. glandula and C. dalli counts =	5880 Live (87S*) 3102 Dead (3102S*)	4536 Live (0 S*) 0 Dead
Mean/dm^2	93.3 live 49.3 dead (35% D)	90.8 live 0.0 dead

*S = oil on shells

(Count of Pachygrapsus crassipes for 10m^2 Sausalito transect was 59 live, 1 dead for May, 1971)

Sausalito transect - Comparison of barnaçle counts according to amount of residual oil on square decimeter plots

dm^2 oil	dm^2	total live	total dead	live/dm^2	dead/dm^2	% live	% dead	ratio L:D
none	16	1406	232	87.9	14.5	85.8%	14.2%	6:1
+	32	4030	1883	125.9	58.8	68.2%	31.8%	2:1
++	10	359	352	35.9	35.2	50.5%	49.5%	1:1
+++	2	55	97	27.5	48.5	36.2%	63.8%	1:2
++++	3	30	538	10.0	179.3	5.3%	94.7%	1:18
May,1971=	63	5880	3102	93.3	49.3	65.5%	34.5%	2:1

95% confidence interval for population mean of dead barnacles per square decimeter is:

$$36 \leq \mu \leq 62$$

APPENDIX 6

STINSON BEACH TRANSECT

Major Species

Date	m^2		Emerita analoga	Nepthys californiensis	Orchestoidea californiana	all three species
7/15/65	9	total	71	47	24	142
		average	7.9	5.2	2.7	15.8
2/17/70	9	total	68	28	6	102
		average	7.6	3.1	0.7	11.3
4/16/71	9	total	10	0	0	10
		average	1.1	0	0	1.1
7/23/71	10	total	16	0	0	16
		average	1.6	0	0	1.6

Test for significant difference between population means:

H_0: $\mu_1 = \mu_2$ H_1: $\mu_1 \neq \mu_2$

Decision rule: Reject H_0 if $t \geq 2.110$ or ≤ -2.110

Test for--	July, 1965 and Feb, 1970	Feb, 1970 and Apr, 1971
t =	0.484	2.125
Decision =	H_0 is true	Reject H_0
		Interval estimate of difference: .03 to 20.37

DRAKES BEACH TRANSECTS

Major Species

Date	m^2		Emerita analoga	Nepthys californiensis	Orchestoidea californiana	all three species
6/25/70	30	total	940	183	0*	1123
		average	31.3	6.1	0	37.4
4/20/71	10	total	131	13	0*	144
		average	13.1	1.3	0	14.4
8/4/71	10	total	40	31	0*	71
		average	4.0	3.1	0	7.1

*20 off transect site

APPENDIX 7

1971 OIL SPILL STUDY TRANSECTS FOR DUXBURY REEF

Transect	Pre-oil Data	Main Species
A-1 = 10 m^2	1969	Tegula sp.
A-2 = 10 m^2	1969	Tegula sp.
A-3 = 10 m^2	1969	Tegula sp.
A-4 = 10 m^2	1969	Tegula sp., Acmaea spp., Pollicipes sp., Littorina sp.
A-5 = 10 m^2	1969	Tegula sp., Acmaea spp., Pollicipes sp., Mytilus sp., Mopalia sp.
A-6 = m^2	1969	Mytilus sp., Balanus sp.
A-7 = 9 m^2	1969	Tegula sp., A. elegantissima
A-8 = 10 m^2	1964	Acmaea spp., Littorina spp. Balanus sp., Chthamalus sp., crabs
A-9 = 10 m^2	1964	(same as transect A-8)
A-10= 10 m^2	1971	(same as transect A-8)
A-11= m^2	1971	Strongylocentrotus sp.
A-12= m^2	1971	Platyodon sp.
B-1 = 10 m^2	1969	Tegula sp.
B-2 = 10 m^2	1969	Tegula sp., Acmaea spp.,Littorina sp.
B-3 = 10 m^2	1969	Tegula sp., Platyodon sp.
B-4 = 10 m^2	1969	Tegula sp., Acmaea spp., Acanthina sp., Mopalia sp.
B-5 = 10 m^2	1969	Acmaea spp., Littorina sp., Mytilus sp., Pollicipes sp.
B-6 = m^2	1959	Herminea smithii
B-7 = m^2	1959	Lottia gigantea
B-8 = m^2	1971	Strongylocentrotus sp.
B-9 = m^2	1971	Platyodon sp.
C-1 = 10 m^2	1969	Tegula sp., Acmaea spp., Mopalia sp.
C-2 = 10 m^2	1969	Tegula sp., Littorina sp., Mytilus sp., Balanus sp., Anthopleura spp.
C-3 = 10 m^2	1965	Mytilus sp., Pollicipes sp., Balanus sp., Chthamalus sp.
C-4 = 10 m^2	1969	Mytilus sp.,Pisaster sp., A. xanthogrammica
C-5 = m^2	1968	Acmaea spp.
C-6 = m^2	1969	Tegula sp., Acanthina sp.
C-7 = m^2	1959	Lottia gigantea
C-8 = m^2	1968	A. xanthogrammica
C-9 = m^2	1962	Saccoglossus sp.
C-10= m^2	1971	Strongylocentrotus sp.
C-11= m^2	1971	Platyodon sp.
C-12= m^2	1967	Haliotis rufescens

APPENDIX 8

DUXBURY REEF BERM DATA

S = oil on shells
T = on top of oil

Berm A-8,9= 20 m^2

Acmaea spp. and Littorina planaxis

Date	$\overline{X}/m^2$
1964, Nov	29.9L
1968, June	29.5L
1969, May	31.0L
1970, Mar	29.9L
1970, June	29.4L
1971, Apr	16.1L 2.8D
1971, July	12.7L 1.9D
1971, Aug	19.7L 1.5D

B E R M A - 8, 9, 10

Date		Acmaea digitalis Acmaea scabra live	dead	Littorina scutulata live	dead	Balanus sp. Chthamalus sp. live	dead
1971, Apr	$\overline{X}$=	31.9	9.2	230.4	20.3	36.4	68.4*
	%=	78%	22%	92%	8%	35%	65%
	ratio=	3L : 1D		11L : 1D		1L : 2D	
	%S	13.6	100	0.2	100	0	97.8
	%T	0.1	-	6.6	-	-	-
	n=	$30m^2$		$10m^2$		$14dm^2$	
1971, July	$\overline{X}$=	24.6	5.2	6.6	.03	12.8	2.2*
	%=	83%	17%	96%	4%	85%	15%
	ratio=	5L : 1D		232L : 1D		5L : 1D	
	%S	13.9	96.6	1.0	-	28.9	71.3
	%T	38.9	-	33.7	-	-	-
	n=	$29m^2$		$280dm^2$		$280dm^2$	
1971, Aug	$\overline{X}$=	31.0	5.2	493.5	1.5	present,	
	%=	86%	14%	99.7%	0.3%		
	ratio=	5L : 1D		329L : 1D		no	
	%S	9.7	96.7	0.6	100		
	%T	14.5	-	44.1	-		
	n=	$29m^2$		$29m^2$		count	

*combined April and July sampling yields a mean of 5 dead per square decimeter, with 95% confidence interval of population mean for dead of 3 to 7 per square decimeter.

Overall Totals for Berm, April, 1971

Square meter and decimeter sampling

Transect	Acmaea spp.	Littorina scutulata	Balanus sp. Chthamalus sp.			
A-8,9	320L, 55D	(present)	(present)	= 320L, 55D	= 85%L, 15%D	
A-10	636L, 222D	2304L,203D	510L,958D	= 3450L,1383D	= 71%L, 29%D	
totals	956L, 277D	2304L,203D	510L,958D	= 3770L,1438D	= 72%L, 28%D	
% dead	22.5%D	8.1%D*	65.3%D	27.6%D for all species		

*95% confidence interval for dead population mean per square meter = $14.6 \leq \mu \leq 26.0$

APPENDIX 9

DUXBURY REEF

AREA C MUSSEL BED TRANSECT DATA

ABALONE TRANSECTS DATA

MUSSEL BED TRANSECT DATA:

Date		Mytilus californianus (10dm² samples per square meter)	Pollicipes polymerus	
12/5/65	2m²	7.5L/dm²	present, no count	
7/8/68	9m²	7.7L/dm²	31.0L/m²	
8/1/69	10m²	5.6L/dm²	31.0L/m²	
1/23/71	10m²	0 dead	present	
4/1/71	10m²	5.9L/dm² 12.6D/m²	24.3L/m²	
6/10/71	10m²	8.1L/dm² 5.0D/m²	24.3L/m²	Balanus glandula
7/23/71	10m²	present	present	9.8L/dm² 10.1D/dm² 95% confidence interval for dead: 6.7 to 13.3

Comparison of Balanus glandula live and dead dm² counts (10 per m²) according to m² oil for July, 1971

m² oil	number of m²	total dead	total live	% dead	ratio D:L
N	0				
+	4	116	410	22%D	1D:3.5L
++	3	117	272	30%D	1D:2.3L
+++	3	772	301	72%D	2.5D:1L
	10	1005	983	51%D	1D:1L

ABALONE TRANSECTS DATA (Tagged Haliotis rufescens):

Duxbury Reef Sites

Date	Island, CT-13	Shark Rock, CT-14	Agate, CT-15
6/23/67	5	2	none
6/26/68	5	2	3
6/23/69	0	0	2
4/30/71	1	0	0
7/8/71	0	2	0

APPENDIX 10 TEGULA FUNEBRALIS COUNTS ON DUXBURY REEF

Total of 11 transects, 100 m^2

No-oil transects = B-3, B-4, 20 m^2
1- 50% oil transects = A-2, A-3, C-6, 21 m^2
51-100% oil transects = A-1, A-5, A-7, B-1, B-2, C-1, 59 m^2

Hypothesis testing-- $H_o: \mu_1 = \mu_2 = \mu_o$ $H_1: \mu_1 \neq \mu_2$

Reject H_o if test statistic $Z \geq 1.96$ or ≤ -1.96, for $n \geq 30$, or
$t \geq t_{n_1+n_2-2}(.025)$ or $\leq -t_{n_1+n_2-2}(.025)$, for $n < 30$

DATE =	June, 1969	July, 1969	Aug, 1969	Apr, 1971	July, 1971	Aug, 1971
All transects						
Mean/m^2	37	31	41	15	35	32
95% C.I.	28 - 46	21 - 53	33 - 49	12 - 18	27 - 43	23 - 40
Test Stat.	7/69 0.92	8/69 -1.46	4/71 5.84	7/71 -4.57	8/71 0.57	8/69 -1.51
Sig. Diff.			Reject H_o	Reject H_o		
Int. Est.			17 - 34	11 - 28		
No-oil transects						
Mean/m^2	35	26	35	20	47	18
95% C.I.	24 - 46	19 - 34	24 - 46	10 - 30	32 - 62	10 - 25
Test Stat.	7/69 1.38	8/69 -1.36	4/71 2.10	7/71 -3.07	8/71 3.59	8/69 -2.76
Sig. Diff.			Reject H_o	Reject H_o	Reject H_o	Reject H_o
Int. Est.			0.6 - 28	9 - 44	12 - 45	4 - 29
All oil transects						
Mean/m^2	38	32	42	14	32	35
95% C.I.	27 - 49	19 - 45	33 - 52	10 - 17	23 - 41	25 - 45
Test Stat.	7/69 0.67	8/69 -1.28	4/71 5.45	7/71 -3.68	8/71 -0.46	8/69 -0.95
Sig. Diff.			Reject H_o	Reject H_o		
Int. Est.			18 - 38	8 - 28		
1-50% oil transects						
Mean/m^2	53	35	53	24	76	90
95% C.I.	21 - 85	9 - 61	25 - 82	19 - 29	53 - 98	65 -115
Test Stat.	7/69 0.91	8/69 -1.00	4/71 2.10	7/71 4.76	8/71 -0.31	8/69 -2.03
Sig. Diff.			Reject H_o	Reject H_o		Reject H_o
Int. Est.			1 - 57	29 - 73		0.1 - 73
51-100% oil transects						
Mean/m^2	33	31	38	10	16	16
95% C.I.	22 - 43	14 - 48	29 - 47	6 - 14	10 - 23	11 - 21
Test Stat.	7/69 0.14	8/69 -0.71	4/71 5.71	7/71 -1.65	8/71 0.12	8/69 -4.27
Sig. Diff.			Reject H_o			Reject H_o
Int. Est.			18 - 37			12 - 32

APPENDIX 11 VISITOR ACTIVITY ON DUXBURY REEF

COMPARISON BETWEEN July 4 - August 7, 1969 AND June 24 - August 10, 1971 (17 days)

ACTIVITY	1969	1971
Fishing	193 11.1%	14 1.9%
Collecting		
Living marine animals	205* 11.8%	61* 8.5%
Other (algae, rocks, etc.)	98 5.6%	14 2.0%
Unknown	73 4.2%	3 0.4%
	376 21.6%	78 10.9%
Not Collecting	1,171 67.3%	625 87.2%
TOTAL VISITORS	1,740 100.0%	717 100.0%

*Average number of organisms collected per collector=

4.4 for 1969
4.2 for 1971

p_1 = 1969 non-collector proportion = .673; q_1 = .327

p_2 = 1971 non-collector proportion = .872; q_2 = .128

H_o: $p_1 = p_2 = p_o$ H_1: $p_1 \neq p_2 \neq p_o$ Reject H_o if $Z \geq 1.96$ or $Z \leq -1.96$

$Z = -10.1$ Reject H_o.

Interval estimate of population proportion difference $= .064 \leq \text{diff.} \leq .232$

There is a difference between the population percentage of non-collectors of 6.4% to 23.2% comparing 1969 to 1971.

APPENDIX 12 DUXBURY REEF MARINE ORGANISM TRANSECTS

Total of 13 transects = 120 m^2 (excluding Area A berm transects and Area C mussel bed transect)

No-oil transects = B-3, B-4, B-5, 30 m^2
1- 50% oil transects = A-2, A-3, C-4, C-6, 31 m^2
51-100% oil transects = A-1, A-5, A-7, B-1, B-2, C-1, 59 m^2

Hypothesis testing— $H_0: \mu_1 = \mu_2 = \mu_0$ $H_1: \mu_1 \neq \mu_2$

Reject H_0 if test statistic $Z \geq 1.96$ or ≤ -1.96

A. FOR ALL SPECIES COUNTED

DATE =	June, 1969	July, 1969	Aug, 1969	Apr, 1971	July, 1971	Aug, 1971
All transects						
Mean/m^2	80	80	90	36	51	70
95% C.I.	56 - 104	53 - 107	63 - 117	27 - 45	40 - 62	53 - 87
Test Stat	7/69 0	8/69 -0.50	4/71 3.64	7/71-2.01	8/71 -1.77	8/69 -1.20
Interval estimate of difference =			Reject H_0 25 - 83	Reject H_0 1 - 29		
No-oil transects						
Mean/m^2	165	190	196	79	86	145
95% C.I.	95 - 235	102 - 278	110 - 282	53 - 105	61 - 111	90 - 200
Test Stat	7/69 -0.43	8/69 -0.10	4/71 2.54	7/71-0.38	8/71 -1.91	8/69 -0.98
Interval estimate of difference =			Reject H_0 27 - 207			
All-oil transects						
Mean/m^2	52	43	55	22	39	45
95% C.I.	32 - 72	26 - 60	37 - 73	16 - 28	27 - 51	34 - 56
Test Stat	7/69 0.66	8/69 -0.97	4/71 3.42	7/71-2.52	8/71 -0.74	8/69 -0.38
Interval estimate of difference =			Reject H_0 14 - 53	Reject H_0 3 - 30		
1-50% oil transects						
Mean/m^2	45	26	46	17	58	64
95% C.I.	8 - 82	6 - 45	11 - 82	12 - 22	33 - 84	41 - 87
Test Stat	7/69 0.91	8/69 -0.99	4/71 1.58	7/71-3.09	8/71 -0.31	8/69 -0.81
Interval estimate of difference =				Reject H_0 15 - 67		
51-100% oil transects						
Mean/m^2	56	52	60	24	29	34
95% C.I.	31 - 80	28 - 76	40 - 81	15 - 34	18 - 39	23 - 45
Test Stat	7/69 0.21	8/69 -0.51	4/71 3.13	7/71-0.67	8/71 -0.82	8/69 -2.10
Interval estimate of difference =			Reject H_0 13 - 58			Reject H_0 1 - 48

B. FOR ALL SPECIES, EXCLUDING TEGULA SP. for 13 transects

Mean/m^2	49	53	56	23	21	43
95% C.I.	26 - 72	26 - 80	29 - 83	14 - 32	12 - 30	26 - 60
Test Stat	7/69 -0.22	8/69 -0.15	4/71 2.23	7/71 0.30	8/71 -2.14	8/69 -0.78
Interval estimate of difference =			Reject H_0 4 - 62		Reject H_0 2 - 42	

APPENDIX 12 - continued

SUMMARY for 13 TRANSECTS, Mean of live counts per square meter

P/number = species present, no count / number of transects (m^2 omitted from computation of mean)

*P = species present, count for this date; total additional count given below as memo only

All oil and no-oil transects 120 m^2 13 transects	A. xanthogrammica	A. elegantissima	Balanus/Chthamalus	Pollicipes sp.	Pachygrapsus sp. Hemigrapsus sp.	Cancer sp. Pugettia sp. Pagurus spp.	Mopalia sp.	Mytilus sp.	Platyodon sp.	Acmaea spp.	Haliotis sp.	Littorina sp.	Tegula sp.	Acanthina sp.	Pisaster sp.	Strongylocentrotus sp.	Mean/square meter for all species	Mean/square meter for all species excluding Tegula sp.
June, 1969	P/1	1.6 P/3	P/3	1.1	P/1	.01 P/1	0.3	1.1 P/2	P/2	35.5 P/2		9.2 P/2	31.4	4.7	0.3	0.1	80.6	49.2
July, 1969	P/1	1.6 P/3	P/3	0.9	P/1	P/1	0.2	0.8 P/2	P/2	44.4 P/2		9.2 P/2	25.8	1.8	0.3	.02	79.6	53.8
Aug, 1969	P/1	1.6 P/3	P/3	0.9	P/1	P/1	0.2	0.8 P/2	P/2	44.2 P/2		9.2 P/2	33.8	4.7	0.4	3.1	90.5	56.7
Apr, 1971	P/1	3.2 P/3	L&D P/4	1.5	0	.03	0.5	1.2 P/2	P/2	17.2 P/1		0 P/2	12.8	0.7	0.2	0.1	36.4	23.6
July, 1971	P/1	1.0 *P/3	L&D *P/5	1.5	.03	.5	0.3	1.2 P/2	P/2	18.5 P/3		0 P/3	29.5 *	1.8	0.3	0.1	51.2	21.7
Aug, 1971	P/1	1.3 P/3	L&D **P/6	2.5	.01 *	.6	0.5	1.0 P/2	P/2	44.5 *P/3		0 P/3	26.8	0.9	0.2	0.1	69.8	43.4
additional total counts		*2424 /1	*261L 1717D **768L 158D		*1D					*275L 27D			*3D					

APPENDIX 12 - continued

SUMMARY FOR 13 TRANSECTS, Mean of live counts per square meter

P/number = species present, no count / number of transects (m^2 omitted from computation of mean)

*P = species present, count for this date; total additional count given below as memo only

No Oil transects B-3,B-4,B-5 30 m^2 3 transects	A. xanthogrammica	A. elegantissima	Balanus/Chthamalus	Pollicipes sp.	Pachygrapsus sp. Hemigrapsus sp.	Cancer sp. Pugettia sp. Pagurus spp.	Mopalia sp.	Mytilus sp.	Platyodon sp.	Acmaea spp.	Haliotis sp.	Littorina sp.	Tegula sp.	Acanthina sp.	Pisaster sp.	Strongylocentrotus sp.	Mean/square meter for all species	Mean/square meter for all species excluding Tegula sp.
June, 1969		P/1	P/1	1.2		.03	0.7	P/1	P/1	118.4		16.7	23.7	4.1		0.3	165.0	141.4
July, 1969		P/1	P/1	0.9		0	0.4	P/1	P/1	151.7		16.7	17.8	2.3		0.1	189.9	172.0
Aug, 1969		P/1	P/1	0.9		0	0.5	P/1	P/1	151.7		16.7	23.3	3.2		0.2	196.6	173.2
Apr, 1971		P/1	L&D P/1	0.2		0.1	1.1	P/1	P/1	63.4		0	13.7	0.4		0.4	79.2	65.5
July, 1971		P/1	L&D P/1	0.3		.03	0.2	P/1	P/1	53.6		0	31.6	0.8		0.4	86.7	55.2
Aug, 1971		P/1	*L&D 100 dm^2	0.3		0.5	0.7	P/1	P/1	131.4		0	12.0	0.4	0.1	0.3	145.7	133.7
additional total counts			*768L 158D (17%D)															

APPENDIX 12 - continued

SUMMARY FOR 13 TRANSECTS, Mean of live counts per square meter

P/number = species present, no count / number of transects (m^2 omitted from computation of mean)

*P = species present, count for this date; total additional count given below as memo only

All oil transects 90 m^2 10 transects	A. xanthogrammica	A. elegantissima	Balanus/Chthamalus	Pollicipes sp.	Pachygrapsus sp. Hemigrapsus sp.	Cancer sp. Pugettia sp. Pagurus spp.	Mopalia sp.	Mytilus sp.	Platyodon sp.	Acmaea spp.	Haliotis sp.	Littorina sp.	Tegula sp.	Acanthina sp.	Pisaster sp.	Strongylocentrotus sp.	Mean/square meter for all species	Mean/square meter for all species excluding Tegula sp.
June, 1969	P/1	2.1 P/2	P/2	1.0	P/1	P/1	0.1	1.4 P/1	P/1	4.0 P/2		5.6 P/2	34.0	4.9	0.5		52.4	18.4
July, 1969	P/1	2.1 P/2	P/2	0.9	P/1	P/1	0.2	1.0 P/1	P/1	3.7 P/2		5.6 P/2	28.5	1.6	0.4		43.3	14.4
Aug, 1969	P/1	2.1 P/2	P/2	0.9	P/1	P/1	0.1	1.0 P/1	P/1	3.6 P/2		5.6 P/2	37.3	5.2	0.6		55.8	17.8
Apr, 1971	P/1	4.1 P/2	L&D P/4	2.0			0.4	1.5 P/1	P/1	1.6 P/1		0 P/2	12.5	0.8	0.2	.01	22.1	9.6
July, 1971	P/1	1.2 *P/2	*P/4	3.2	.04	0.7	0.3	1.5 P/1	P/1	3.2 P/3		0 P/3	28.8 *	2.1	0.4	.01	39.3	10.3
Aug, 1971	P/1	1.6 P/2	P/5	3.2	.01 *	0.6	0.4	1.3 P/1	P/1	6.7 *P/3		0 P/3	31.7	1.0	0.3		45.4	13.3
additional total counts		*2424/1	*261L, 1717D/2		*1D					*275L, 27D/2			*3D					

APPENDIX 12 - continued

SUMMARY for 13 TRANSECTS, Mean of live counts per square meter

P/number = species present, no count / number of transects (m^2 omitted from computation of mean)

*P = species present, count for this date; total additional count given below as memo only

1-50% Oil transects A-2,A-3 C-4,C-6 $31m^2$ 4 transects	A. xanthogrammica	A. elegantissima	Balanus/Chthamalus	Pollicipes sp.	Pachygrapsus sp. Hemigrapsus sp.	Cancer sp. Pugettia sp. Pagurus spp.	Mopalia sp.	Mytilus sp.	Platyodon sp.	Acmaea spp.	Haliotis sp.	Littorina sp.	Tegula sp.	Acanthina sp.	Pisaster sp.	Strongylocentrotus sp.	Mean/square meter for all species	Mean/square meter for all species excluding Tegula sp.
June, 1969	P/1	P/1	P/1		P/1	P/1		P/1	P/1	P/2		P/2	36.0	8.3	1.3		45.6	9.6
July, 1969	P/1	P/1	P/1		P/1	P/1		P/1	P/1	P/2		P/2	23.7	1.2	1.2		26.1	2.4
Aug, 1969	P/1	P/1	P/1		P/1	P/1		P/1	P/1	P/2		P/2	36.3	8.8	1.7		46.7	10.5
Apr, 1971	P/1	P/1	L&D P/3		0	0	0.2	P/1	P/1	P/1		*P/2	16.5	0.2	0.6		17.5	1.0
July, 1971	P/1	0.6 *P/1	L&D *P/3		0.1	1.5	.03 .03	P/1	P/1	P/3		P/2	51.4	4.3	1.0		58.8	7.4
Aug, 1971	P/1	0.9 P/1	L&D P/3		*P/1	1.2	.03	P/1	P/1	*P/3		P/2	61.2	0.4	0.7		64.3	3.0
additional total counts		*2424	*165L 1710D/2 (91%D)		*1D					*275L 27D/2 (9%D)		*						

APPENDIX 12 - continued

SUMMARY FOR 13 TRANSECTS, Mean of live counts per square meter

P/number = species present, no count / number of transects (m^2 omitted from computation of mean)

*P = species present, count for this date;
total additional count given below as memo only

51-100% Oil transects A-1,A-5,A-7 B-1,B-2,C-1 59 m^2 6 transects	A. xanthogrammica	A. elegantissima	Balanus/Chthamalus	Pollicipes sp.	Pachygrapsus sp. Hemigrapsus sp.	Cancer sp. Pugettia sp. Pagurus spp.	Mopalia sp.	Mytilus sp.	Platyodon sp.	Acmaea spp.	Haliotis sp.	Littorina sp.	Tegula sp.	Acanthina sp.	Pisaster sp.	Strongylocentrotus sp.	Mean/square meter for all species	Mean/square meter for all species excluding Tegula sp.
June, 1969		2.9 P/1	P/1	1.5			0.2	1.9		5.4		8.5	32.9	3.1	.02		56.0	23.1
July, 1969		2.9 P/1	P/1	1.4			0.3	1.4		4.9		8.5	31.5	1.8	0		52.2	20.7
Aug, 1969		2.9 P/1	P/1	1.4			0.1	1.4		4.7		8.5	37.8	3.1	.02		59.9	21.7
Apr, 1971		5.8 P/1	P/1	3.1			0.5	2.3		3.8		0	10.4	1.2		.02	24.6	14.1
July, 1971		1.5 P/1	*60 dm^2	4.9		0.2	0.5	2.3		3.8		P/1	16.7 *	0.9		.02	28.9	12.1
Aug, 1971		1.9 P/1	P/2	4.9	.02	0.3	0.6	2.0		7.8		P/1	16.2	1.3	.02	0	34.8	18.6
additional total counts			*96L 7D (7%D)										*3D					

APPENDIX 13

LIVE and DEAD COUNTS FOR OIL EXPOSURE LABORATORY TESTS, December 3, 1971

(after 28 days of exposure)

SPECIES	CONTROL TANKS			CONDITIONED TANKS			UNCONDITIONED TANKS			TOTAL - OIL TANKS		
	live	dead	% dead	live	dead	% dead	live	dead	% dead	live	dead	% dead
Balanus glandula	44	12	21%	51	62	55%	85	28	25%			
Pollicipes polymerus	43	57	57%	85	67	44%	11	85	89%			
Mytilus californianus	30	0	0%	30	0	0%	30	0	0%			
Pachygrapsus crassipes	4	1	20%	3	2	40%	4	3	43%			
Hemigrapsus nudus	1	0	0%	1	0	0%	-	-	-			
Acmaea digitalis	4	2	33%	3	3	50%	3	3	50%			
Acmaea scabra	6	0	0%	4	2	33%	1	5	83%			
Tegula funebralis	26	0	0%	26	0	0%	26	0	0%			
Totals and overall % =	158	72	31%	203	136	40%	160	124	44%			
Barnacles, mussels and limpets				173	134	44%	130	121	48%	303	255	46%
Crabs and snails				30	2	6%	30	3	9%	60	5	8%

APPENDIX 14 SPECIES COUNTED IN TRANSECT STUDIES

COELENTERATA

Anthopleura xanthogrammica (Brandt, 1835)
Anthopleura elegantissima (Brandt, 1835)

ANNELIDA

Nephtys californiensis Hartman, 1938

ARTHROPODA

Orchestoidea californiana (Brandt, 1851)
Emerita analoga (Stimpson, 1857)
Pagurus samuelis (Stimpson, 1857)
Pagurus spp.
Pachygrapsus crassipes Randall, 1839
Hemigrapsus nudus (Dana, 1851)
Cancer antennarius Stimpson, 1865
Pugettia producta (Randall, 1839)
Pugettia gracilis Dana, 1851

MOLLUSCA

Mopalia muscosa (Gould, 1846)
Balanus glandula Darwin, 1854
Chthamalus dalli Pilsbry, 1916
Pollicipes polymerus (Sowerby, 1833)
Mytilus californianus Conrad, 1837
Platyodon cancellatus (Conrad, 1837)
Acmaea digitalis Eschscholtz, 1833
Acmaea scabra (Gould, 1846)
Lottia gigantea Sowerby, 1843
Haliotis rufescens Swainson, 1822
Tegula funebralis (Adams, 1854)
Littorina scutulata Gould, 1849
Littorina planaxis (for berm only) Philippi, 1847
Acanthina spirata (Blainville, 1832)
Hermaeina smithi Marcus, spec. nov.

ECHINODERMATA

Pisaster ochraceus (Brandt, 1835)
Pisaster brevispinus (Stimpson, 1857)
Strongylocentrotus purpuratus (Stimpson)

CHORDATA

Saccoglossus sp.

APPENDIX 15

SUMMARY OF SPECIES WITH DEAD COUNTS (January-August, 1971)

Site	Species	Sample counts	sample mean for dead	Total dead based on sample mean	Total dead based on 95% confidence interval for population mean for dead
SAUSALITO (Bridgeway area only = 1,000 m^2)					
	P. crassipes	42L, 58D = 58%D	58 total	58	58
	B. glandula	5880L, 3102D = 35%D	49/dm^2	4,900,000	3,600,000 to 6,200,000
STINSON BEACH (transect area only = 1,000 m^2)					
	E. analoga, N. californiensis, O. californiana	(from 102 to 10) 10L, 92d = 91% decrease	10/m^2	10,000	10,000
DUXBURY REEF					
Berm (Area A only = 75 m^2)					
	P. crassipes	(from 200 to 35) 35L, 165d = 83% decrease	165 total	165	165
	Acmaea spp.	956L, 277D = 22%D	9/m^2	675	(150) 277 to 1,200
	L. scutulata	2304L, 203D = 8%D	20/m^2	1,500	1,050 to 1,950
	B. glandula	4107L, 1574D = 27%D	5/dm^2	37,500	22,500 to 52,500
Mussel Beds (Area C only = 1,000 m^2)					
	M. californianus	5920L, 126D = 2%D	12/m^2	12,000	12,000
	P. polymerus	(from 310 to 243) 243L, 67d = 23% decrease	7/m^2	7,000	7,000
	B. glandula	938L, 1005D = 51%D	10/dm^2	1,000,000	600,000 to 1,300,000
	For all sites =	20435L, 6669D = 25%D		5,968,898	4,253,050 to 7,584,873
	For Duxbury Reef*=	14503L, 3417D = 20%D		1,058,840	642,992 to 1,374,815

*Note: The above dead counts are only for selected areas. Other sections of the reef had oil, but the counts are not included in the above estimates.

D 3102
L 87
3189
.97
22323
28701
309333

Chan

Erratta

p. 6 26:50%, treated

p. 17 = S/B 3,189 last sent.

p 21 = Contaminated 9th line

other algae = Urospora instead of Enteromorpha

A STUDY OF THE EFFECTS

OF THE SAN FRANCISCO OIL SPILL ON MARINE ORGANISMS

PART I

by

Gordon L. Chan

January, 1972

College of Marin

Kentfield, California 94904

COLLEGE OF MARIN

June 29, 1972

Dr. J. A. Spence
Coordinator
Environmental Health, Pollution, & Toxicology
Standard Oil Company of California
225 Bush Street
San Francisco, California 94120

Dear Dr. Spence:

My studies of marine life recruitment from the San Francisco oil spill of January 1971 have revealed some interesting developments. This progress report is but a glimpse of the return of some marine organisms to the environment affected by the Bunker C oil throughout the Marin County intertidal zone. My total studies will be published in the Part II report to be released in the spring of 1973. However, let me briefly highlight some of the findings for just the oil-affected Sausalito Seal Rock area in regard to two sessile or sedentary species. (See enclosed data sheet.)

1. The living acorn barnacles, Balanus glandula, have nearly tripled in total counts. Hundreds of young barnacles, less than 1 mm in diameter, have occupied the rocky areas where the oil has flaked off. Some have even settled on the old barnacle base scars. The mean count in May of 1971 was 93 per square decimeter. One year later, in May of 1972, the mean was 278 per square decimeter for the same transect! The data from this random sampling indicates to me that planktonic larval barnacle populations in the bay appeared to be following a normal pattern this past year.

2. Because of the recruitment, the percentage of dead barnacles in the transect decimeters has dropped from a 34.5% in 1971 to 3.9% in 1972.

3. The limpets, Acmaea spp., have also illustrated some changes. In 1971, 21 limpets were counted in 63 random square decimeters. In 1972, 90 were counted in 60 random square decimeters.

In summary, there is a significant increase in the population of barnacles and limpets. Although not illustrated by a chart on the enclosed data sheet, the population of the purple shore crab, Pachygrapsus crassipes, remained about the same, 6 per square meter in 1971 to 4 per square meter in 1972.

Feel free to contact me if you have any questions about this brief progress report.

Sincerely,

Gordon L. Chan

Gordon L. Chan, Ph.D.
Director of Marine Technology Programs

GLC:mc
Encl.

KENTFIELD
CALIFORNIA 94904
TEL (415) 454-3962

Dr. G. Chan
June 29, 1972

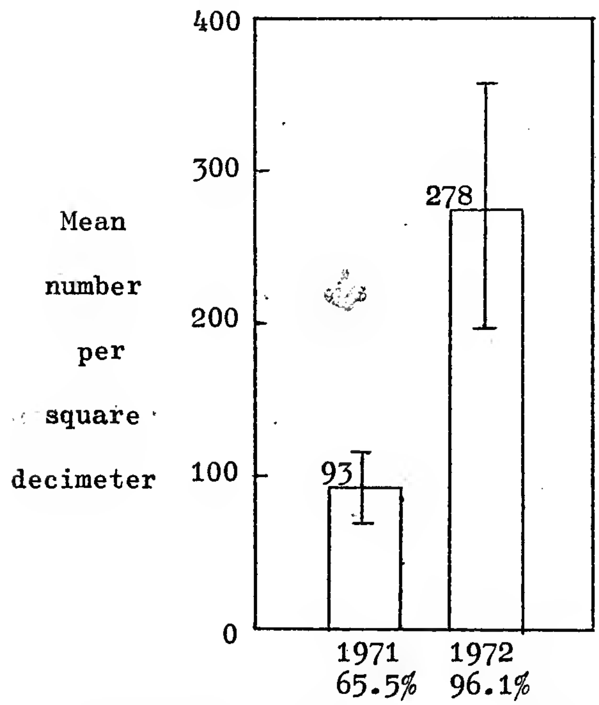
Figure 3

SAUSALITO TRANSECT DATA

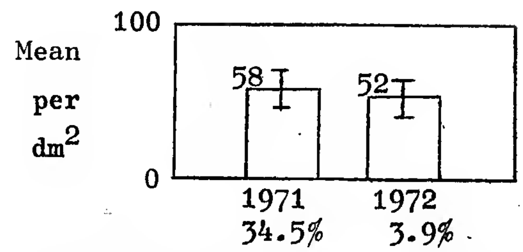
Ten square-meter transect with decimeter sampling
for Balanus glandula (acorn barnacle) and Acmaea spp. (limpet)

COMPARISON CHARTS FOR May 13, 1971 -- 76%-100% transect oil
May 18, 1972 -- 26%- 50% transect oil

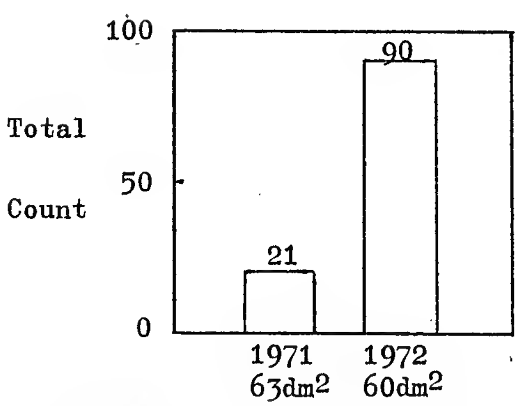
I = 95% confidence interval for population mean



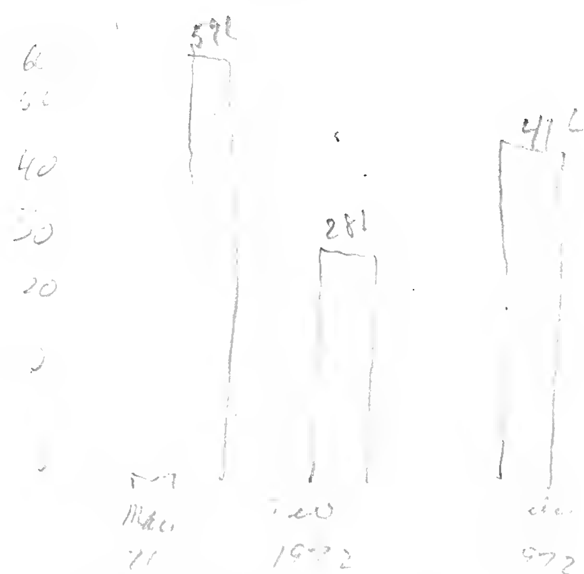
3 Live Balanus glandula



Dead Balanus glandula



Live Acmaea spp.



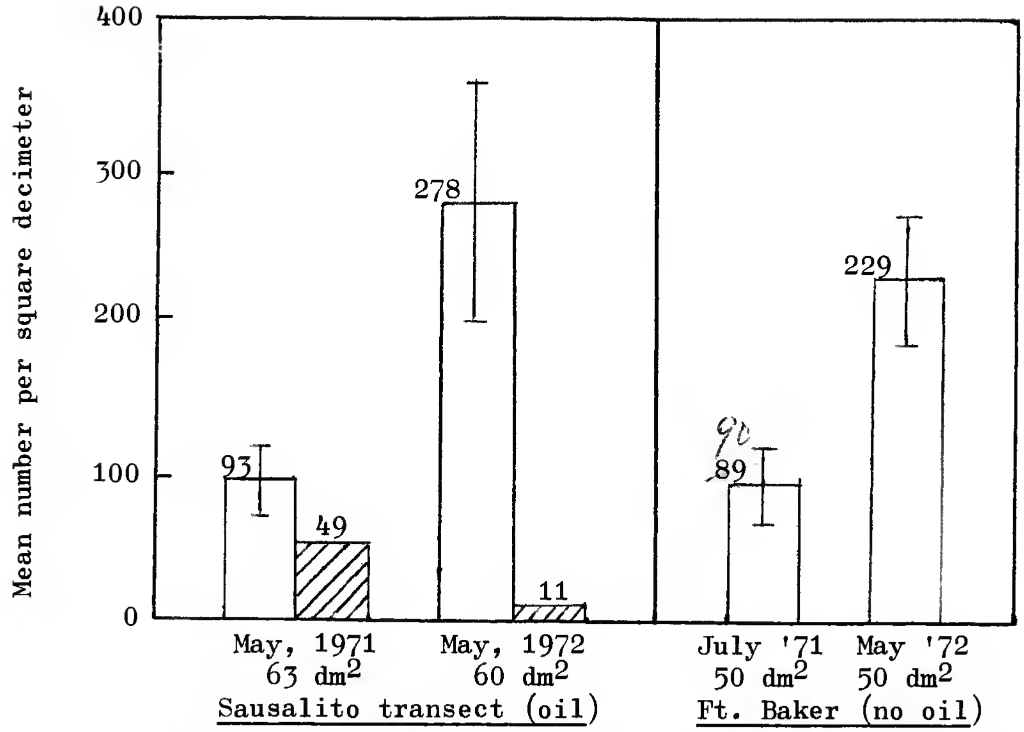
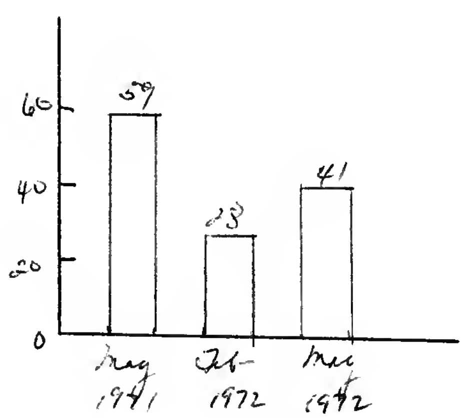


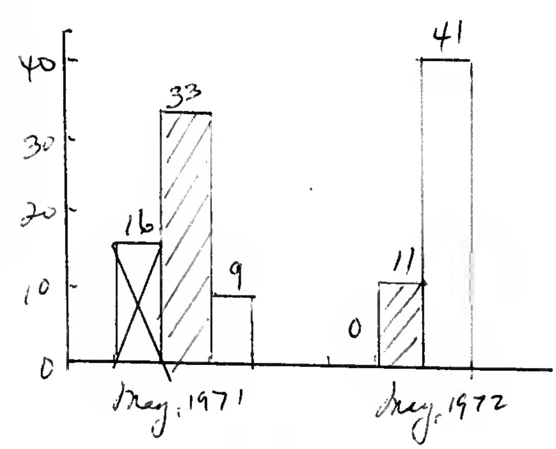
Figure Comparison of barnacles, Balanus glandula and Chthamalus dalli, for transects in Sausalito (oil) and Ft. Baker (no oil)

live dead 95% confidence interval for population mean



Sausalito (oil)

Pachygrapsus
Hemigrapsus



Sausalito (oil)

DEAD BAL/CHTH

animals in shells

empty shell

scars (indeterminate age)